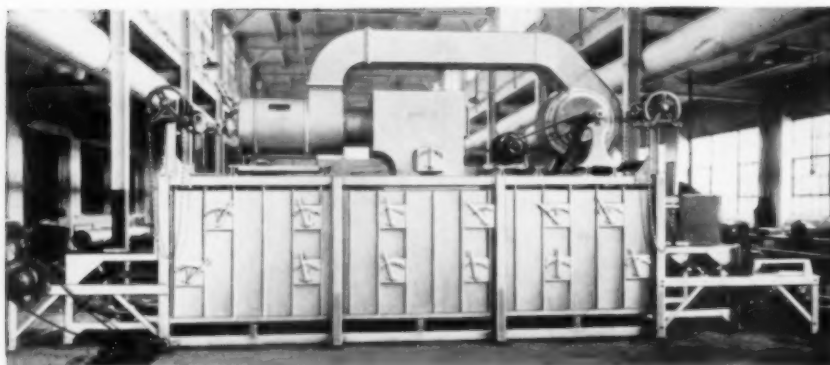


AUG 7 1935



Metal PROGRESS

THE AMERICAN SOCIETY FOR METALS



The view at the left shows location of Standard Air Heater and fan which circulates the heated air through the furnace. The single burner on the air heater (shown below) supplies sufficient air to heat the work to 700°F. in 30 minute cycles.

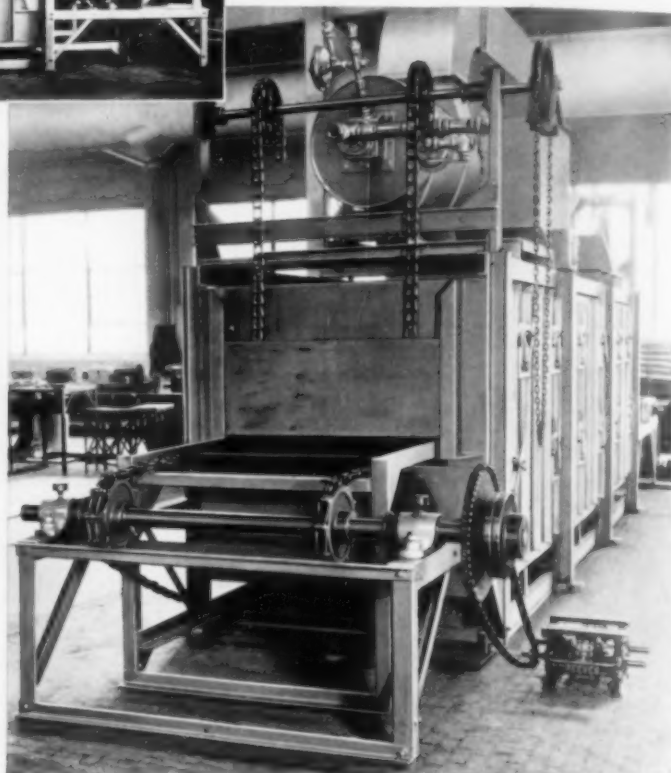
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Heated by convected air from a Standard S. C. Air Heater.

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Fuel Consumption: 375 cu. ft. per hour, 1000 B. T. U. gas.

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Rockwell Hardness	Before Annealing	—After Annealing
End Middle End	70 75 69½	35 35 34½

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METAL PROGRESS

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August, 1935

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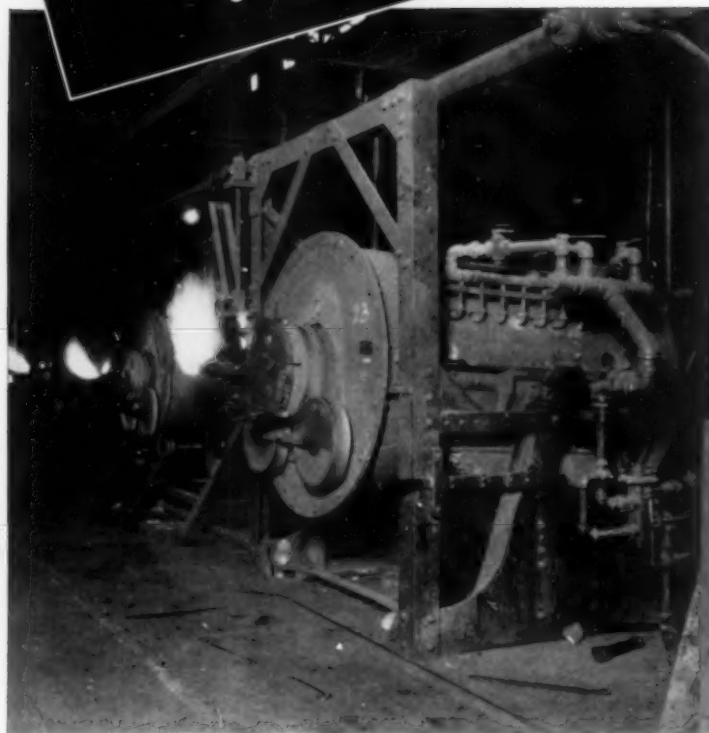
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Editorial Introduction

 TWENTY PAGES in a single issue devoted to the question "What is troostite and sorbite?" would be unwarranted were it not that the proper use of these terms is influenced by recent important discoveries about the transformations occurring in steel during quenching. Certainly something so fundamental is worth the space.

The Editor is one who was schooled with the proposition that austenite decomposes through a regular series of unstable structures named martensite, troostite, and sorbite to pearlite, and that this series of transformations occurs regularly even on slow cooling, slow enough to form pearlite, as well as upon the tempering of quickly cooled martensite. This conception is put forward in the textbooks most widely used and is briefly defended by Dr. Honda on page 34. Unfortunately it does not harmonize very well with recent investigations by our leading metallographers into the structures called troostite produced in the two different ways. Everyone knew that the gross structure was different—one was nodular and the other acicular—but now it seems proven that the fine structure is also different, the first being very fine pearlite and the other having no sign of stratification (on higher tempering, the first identifiable particles of cementite are globules rather than platelets).

It seems reasonable to believe that if martensite is always the first step in the transformation of austenite, next troostite, next sorbite, next pearlite, and lastly globular cementite, the resulting structure from its *complete* decomposition should be the same. But a very slowly cooled steel is coarsely pearlitic with lamellar cementite, whereas a quenched steel after a high draw is sorbitic, where the carbides are in little particles. Furthermore, the structure resulting from slightly-too-slow quenching and the first decomposition product of mild tempering should be the same. One, however, is certainly nodules of finest pearlite whereas the other is an acicular structure irresolvable by an equally good microscope.

Identical intermediate steps should not produce such different end products.

It then remains to be explained how austen-

ite can transform in two such different ways—direct to pearlite at temperatures between the A_1 and 1000° F., and direct to martensite at temperatures below 400° F. One of the Editor's friends with a leaning toward mathematical physics assures him that this does not violate any of the laws of thermodynamics, but he has had to take that statement on faith.

A non-mathematical view is presented by Dr. Van Horn in the article immediately following, who points out that the transformation of austenite involves two separate actions—first is the change of gamma iron into alpha iron, which involves rather small atomic movements but whose tendency to act increases slowly with the degree of undercooling; and second is the accumulation of insoluble carbon atoms to form a particle of cementite, which involves rather extensive atomic movements, and rapidly increases in speed with rising temperature.

According to these conditions, carbide movement is virtually impossible in cold metal, hence at low temperatures, say 300° F., the first action occurs more or less completely by "trigger action" but none of the second; hence we have martensite. At higher temperatures, say 1000° F., the speed at which the second action occurs is many hundred times as great as the $\gamma \rightarrow \alpha$ allotropic change (undercooled relatively little) and a molecule of cementite therefore forms *immediately* when an atom of carbon is released from solution and attaches itself to the edge of one of many crystals growing out radially from favored nuclei into the slowly transforming austenite. Transformation also appears to occur only at the front of these growing nodules, relatively few in number. Hence nodular fine pearlite.

On tempering martensite, cementite crystallizes from a greatly undercooled and unstable solution, and at a multitude of centers, but the temperature is so low that the bulky cementite molecule cannot travel far from its birthplace, and when it does may attach itself to any one of many nearby particles. Hence tempering of martensite causes growth of cementite globules, finally reaching visibility and we have sorbite.

Several months ago, intrigued by a lecture by Dr. Desch at Cornell University on the theory of hardening, the Editor asked Dr. Van Horn to present, as simply as may be, the X-ray evidence about the various constituents of steel — and here is the happy result

The Components of Steel

Austenite, Martensite, Pearlite, Sorbite

■ ALLOYS OF IRON AND CARBON are of great commercial importance and constitute one of the most complicated metallographic series. The capacity for enormously increasing in hardness after quenching from a sufficiently high temperature is the most outstanding property which distinguishes steel from other alloys; it has been known for over 3000 years and has been the subject of extensive and intensive investigations.

Hardening of steel is understood and applied practically, but a satisfactory explanation supported by a logical consideration of substantial evidence is yet to be evolved. The result or effect of quenching a high carbon-iron alloy in cold water from above the "critical range" is accurately known, but what occurs within the metal has not been definitely determined, notwithstanding a tremendous quantity of experimental labor, and many divergent theories.

This article describes a few of the recent investigations published in scattered sources concerning the nature of the constituents in hardened carbon steel, and does not attempt to explain the hardening mechanism. It assumes that the reader is acquainted with the elements of crystallography and X-ray analysis, whereby the atomic spacings and locations in solids may be determined.

By Kent R. Van Horn
Aluminum Co. of America
Cleveland, Ohio

Austenite — Unless otherwise stated, "carbon steel" for the purpose of the present discussion is pure iron alloyed with from zero to 1.7% carbon. For simplicity the potent modifying effects of other alloying elements, non-metallic impurities, and insoluble particles of "dirt" are not considered.

At temperatures above A_3 all such carbon steels can form a homogeneous, non-magnetic solid solution called austenite which is universally regarded to be carbon (or possibly cementite) dissolved in crystals of gamma iron. Atoms of gamma iron form a face-centered cubic space lattice; the unit cube has an edge dimension of 3.56 Ångstrom units. The doubt may arise as to whether the carbon is distributed in gamma iron, atom by atom, and if so where, or is in the form of molecules of iron carbide Fe_3C — that is, a combination of four atoms arranged in required spatial relations.

A. Westgren, and later G. Hägg, determined by precision X-ray methods that the carbon atoms are dispersed in the spaces between the iron atoms, an "interstitial solid solution," thereby effecting a slight enlargement of the unit cell with increasing carbon content. The largest available interstices in the lattice would permit an atomic radius of 0.52 Å, whereas the radius of the carbon atom in the diamond crystal is 0.77 Å. Certainly an iron carbide molecule consisting of three atoms of iron (ascribed radius 1.26 Å each) and one carbon atom could not be compressed to that dimension. Furthermore, complex cementite molecules would not be expected — from the

nature of atomic forces—to diffuse in gamma iron at as low a temperature as 1300° F. (700° C.), that is, above A_1 . Carbon appears therefore to be the solute in austenite.

The Austenite to Martensite Reaction

If allowed to cool slowly, the solid solution austenite transforms at A_{r1} —about 1300° F.—into ferrite and cementite. Ferrite is a magnetic form of iron, crystallizing in a body-centered cubic space lattice with a parameter of 2.86 Å. Cementite has about the composition represented by the chemical formula of the iron carbide Fe_3C , and has an exceedingly complicated unit cell; the approximate atomic arrangement is illustrated in METAL PROGRESS for July, 1931.

Rapid cooling of carbon steels retards the above normal separation of the phases ferrite and cementite. The degree of retardation or "undercooling" increases with the speed of cooling. The transformation can be entirely suppressed by the addition of alloying elements to steel, but not in the plain carbon series even drastically quenched in salt water. Carbon steel quenched in water or oil to give maximum hardness consists chiefly of "martensite," a very familiar term glibly used in heat treating practice but with timidity by metallurgists.

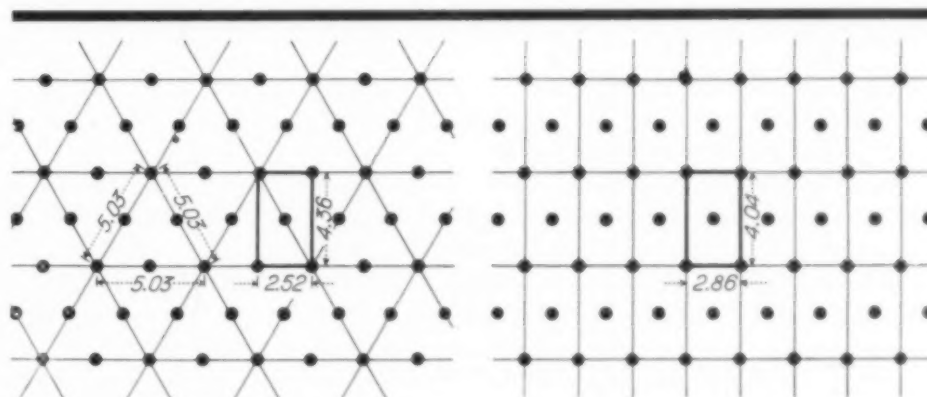
Martensite, differing from the face-centered austenite, is magnetic, indicating that the iron is of the body-centered type of space lattice—at least partially. The freshly quenched structure etches slowly and is metallographically recognized as fine, brilliant, white needles or rods, which probably represent cross sections of plates. (see Fig. 15, page 31). Martensite is consequently formed by the transformation of a solid solution of carbon in gamma iron to a supersaturated solid solution of carbon in body-centered iron.

The needles shown on a microsection tend to precipitate as plates parallel to the {111} planes in a crystal of the mother austenite. Recent X-ray data have defined that the {011} planes of the body-centered cubic iron are aligned parallel to the {111} austenite planes. The sketch shows that the atomic arrangement and

interatomic distances on these planes are similar, and the transformation can occur with but minor movements of the atoms in space.

It is agreed that the grain size of austenite in a carbon steel at, say, 1500° F. is fairly large. The standardized grain size charts and numbers from 1 to 8 refer to the dimension of the austenitic grains at the temperature in question. The grain size of martensite, a decomposition product, is debatable—the X-ray and microscope may be unreliable for the determination for the following reasons: The directional crystallographic precipitation may generate a myriad of submicroscopic grains oriented approximately parallel within certain regions, and these would cooperate to render similar etching and X-ray effects. Furthermore, the {111} planes of retained austenite and the {011} planes of the transformed iron would produce the same X-ray reflection images, and metallographically the aligned fragments would etch similarly, appearing as a well-defined "needle."

Martensite, aged for an extended period at room temperature or tempered at slightly above room temperature, etches more rapidly than freshly quenched martensite to an acicular development with occasional unresolvable darkened or mottled areas (Fig. 16, page 31). The components of this structure are considered to be body-centered iron needles or platelets (containing some carbon in solid solution) and minute cementite particles. The grinding and polishing incident to metallographic examination, or etching in hot picric acid to procure photographic contrast, often induces tempering effects and results in carbide precipitation. Consequently extreme caution should be exercised in interpreting photomicrographs.



Location and Spacing of Iron Atoms on the {111} Plane of Face-Centered Austenite (at Left) and on the {011} Plane of Body-Centered Cubic Ferrite (at Right) Indicating That the Transformation Occurs With a Minimum of Atomic Movement

The difference in structural appearance of martensite when freshly quenched and after aging or tempering is unfortunately the source of numerous and frequently confusing terms. Black martensite, white martensite, freshly quenched martensite, and aged martensite, α and β , θ and η martensites, and even two stoichiometric combinations or compounds of iron and carbon are some of the galaxy of proposed "types." Many of these "types" or martensitic twins have originated from the improper application or falacious interpretation of data. Nevertheless, there are some important variations in quenched steel depending on the thermal history which need a logical explanation.

W. P. Sykes and Zay Jeffries have clarified the changes in properties of quenched steel at or below room temperature. Careful hardness measurements showed that the transformation from austenite to martensite below room temperature (in liquid oxygen) is relatively independent of the time and dependent only on temperature. The increase in hardness associated with this allotropic change is accompanied by an increase in volume, as required by the transition from the close-packed face-centered to the body-centered cubic lattice.

On the other hand, there are certain hardening effects derived from tempering quenched specimens at low temperatures that are related to both time and temperature. Thus Sykes and Jeffries found that 2300 hr. are required to attain maximum hardness (C-70.0) when aging at room temperature, whereas only 150 hr. are necessary when tempering at 120° F., 30 hr. at 165° F., and 5 hr. at 212° F. Such changes are accompanied by a decrease in volume and respond to the laws of aging. The duration of time at or above room temperature is important, which implies that there is a carbide precipitation and coalescence with increasing temperature.

H. Hanemann and H. J. Wiester have visibly demonstrated the dependence of the allotropic transformation on temperature. They obtained martensitic needles from austenite in a plain

carbon steel by quenching in a molten metal medium at 320° F., then polishing and etching in a holder heated at 212° F. Needles of regular or completed dimensions appear suddenly in relief on a polished surface on lowering the temperature of this specimen below 212° F.—

attributable, of course, to the volume change. As the temperature decreases, new needles are generated in the same manner but there is no growth of the acicular areas that originated at higher temperatures. The instantaneous formation of the needles resembles the production of mechanical twins in zinc, tin, and iron (Neumann bands).

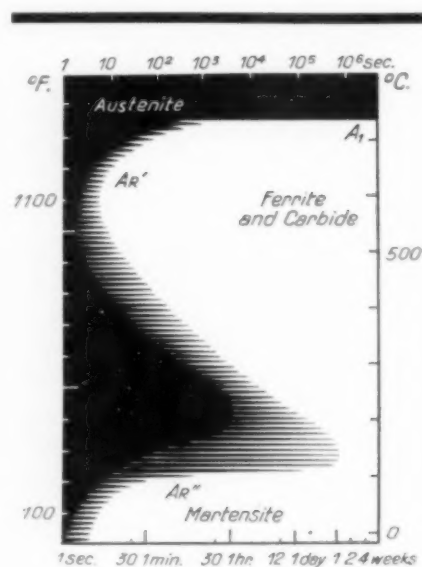
E. C. Bain and E. S. Davenport have also studied the time element in the austenite to pearlite conversion, and confirmed that the time-consuming part of the transition is the carbon migration and carbide agglomeration, and that the iron transformation from face-centered to body-centered, involving only a slight atomic rearrangement, is instantaneous. The schematic representation reproduced on this page from the 1932 Campbell Memorial

Lecture by E. C. Bain illustrates the time interval and importance of temperature to martensite formation. For instance, the diagram shows that at about 300° F. austenite is converted to ferrite and cementite very slowly, requiring weeks to consummate the reaction. At 200° F. the transformation is directly to martensite and is completed in about 10 sec., and at zero even faster.

Constitution of Martensite

It is evident that the decomposition of austenite involves two distinct actions, (a) the allotropic transformation of the iron and (b) the rejection of carbon. Separation of these processes has simplified the conception of the nature of martensite.

Valuable information on the constitution of martensite has been recently contributed by the application of the X-ray. The most significant result has been the discovery of a new iron phase, body-centered tetragonal, in rapidly quenched



Relative Time for Austenite to Become Unstable (Black Area) and to Transform (Horizontal Lines). Note logarithmic scale. End product is ferrite plus carbide, or martensite, depending on temperature of reaction (After Bain)

steels. This phase always is associated with alpha iron in low carbon steels and with austenite in high carbon steels. The relative quantity of this constituent depends on the carbon content and quenching velocity. Tetragonal iron can dissolve appreciable carbon as evidenced by the axial ratio, $c \div a$, of 1.03 for an 0.80% carbon steel and 1.07 for a 1.60% carbon steel. The body-centered cubic iron lattice (ferrite) may be expanded from zero to about 7% along the tetragonal or vertical axis, and contracted from zero to 0.35% in the cubic directions.

Location of Carbon Atoms

Important features which have been intensively studied concern the location of the carbon atoms in this tetragonal lattice. Are the solute atoms still in open spaces within the lattice, as the carbon is in austenite, forming an interstitial or "additive" solid solution, or have one or more carbon atoms displaced an iron atom at certain of their normal positions in the lattice, thus forming a "substitutional" solid solution?

The simple substitutional possibility, where a small carbon atom may be substituted for a large iron atom, is excluded because the quantity of tetragonal deformation increases with the addition of carbon. E. Öhman assumed a complex substitution of two carbon atoms for one iron atom. Later K. Honda and recently G. Hägg satisfactorily established that the carbon atoms are dispersed in the largest spaces between the body-centered tetragonal iron positions, that is, introduced in the tetragonal lattice in addition to the iron atoms, thus an interstitial solid solution similar to austenite. However, Honda complicated the structure by proposing, in addition, a body-centered cubic solution or "beta martensite" in tempered steels. Hägg, by precision parameter measurements, has disproved this assumption by determining that the carbon content of the tetragonal phase diminishes on tempering, thus causing a decrease in the degree of tetragonal deformation. Carbon is rejected after a long period at room temperature, an action increasing in velocity at higher temperatures.

When the tetragonal solution contains less than 0.60% carbon, the characteristic crystallographic symmetry is not detectable. There is thus a region in quenched lower carbon steels, or slightly tempered high carbon steels where it is difficult to distinguish between body-centered cubic iron and slightly body-centered tetragonal iron. Zay Jeffries has suggested the term "body-

centered iron" for this range which would include both types, yet differentiate the atomic arrangement from that of face-centered cubic gamma iron. The X-ray reveals that the tetragonal phase transforms to a mixture of alpha iron and cementite by tempering at 300° F.

Martensite may therefore be regarded as a supersaturated solid solution of carbon in tetragonal and body-centered iron. Microscopically, the term martensite is proposed for the freshly quenched, white, acicular structure containing no carbon precipitation. Carbon is atomically dissolved in the iron of martensite and detectable with the X-ray by the degree of lattice enlargement, producing a tetragonal "deformation." Carbide separation on tempering is revealed first by the discontinuous decrease of the body-centered tetragonal lattice to a cubic cell, later by cementite reflections on an X-ray pattern, and microscopically by dark, mottled, unresolvable regions after etching. When freshly quenched martensite is tempered or subjected unintentionally to tempering effects, the tetragonal and body-centered solution is converted to body-centered cubic iron (ferrite) and iron carbide (cementite) of various particle dimensions depending on the temperature. Of course, a sizable section of hardened steel cannot consist entirely of martensite and may also contain some retained austenite or alpha iron and cementite in some form of aggregation.

Nature of End Product

A view widely maintained and minutely described in many textbooks is that the changes in a steel cooled from above the critical follow in a regular order through the structures named austenite, martensite, troostite, sorbite, pearlite, and spheroidized cementite, and that the final product depends on the speed of cooling. Further, that the same succession of structures appears when freshly quenched martensite is tempered or reheated to higher and higher temperatures for longer and longer times. This concept of the transitions in steel is certainly incorrect, as demonstrated in the original treatise of E. C. Bain and E. S. Davenport and the recent Campbell and Howe Memorial Lectures of Bain. It may be advisable to show how this austenite to pearlite transformation may occur directly without passing through the martensite stage, as defined above—in other words, show that austenite can decompose in at least two entirely different ways.

The postulated definitions of austenite and martensite agree with the fundamental discoveries of Bain and his associates. The structures resulting from the transformation of steels at any temperature in the range between 750 and 1100° F. (400 and 600° C.) definitely indicate that carbon precipitation *immediately* follows the allotropic change. At high temperatures (about 1300° F.) the austenite is converted to coarse lamellar pearlite (ferrite and cementite). At progressively lower temperatures the opportunity for the simultaneous consummation of the atomic readjustment of iron, from face-centered to body-centered cubic, and the carbide separation diminishes until the allotropic change definitely precedes the other, transforming an entire grain before carbon is rejected. The divergence between the two phenomena becomes more pronounced at lower temperatures where carbon diffusion is retarded, until finally at about 200° F. or lower martensite is formed with no carbon precipitation. Bain has incorporated the time-temperature relations of the transitions and resulting structures in the accompanying diagram.

If the allotropic rearrangement occurs slightly in advance of the iron carbide separation, the result is a fine lamellar pearlite, the "radial" or "nodular" type in which F. F. Lucas and E. C. Bain

have succeeded in delineating

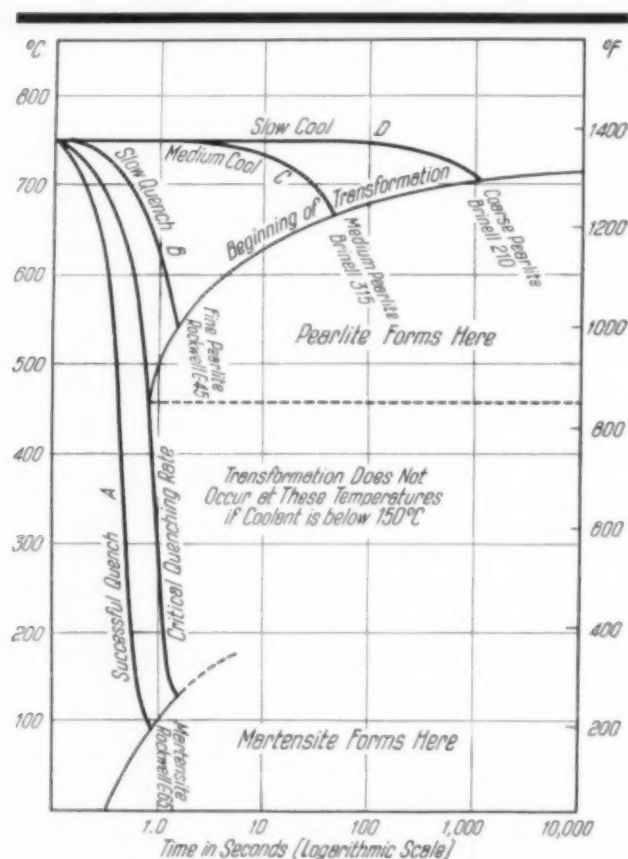
very minute lamellae. Another entirely different structure, termed "martensite-troostite" by some metallographers, is produced when the allotropic change is suppressed to a low temperature and forms martensite which is subsequently tempered and precipitates carbon. This agglomerated cementite of tempered martensite has a different structural appearance from the type obtained directly from austenite at higher temperatures. The carbide rejected at low tempering temperatures is very fine and unresolvable with the best microscopes; it coalesces to granular or globular particles, called sorbite, at higher tempering temperatures. The softening of quenched steels is therefore a process involving the coalescence of carbide particles.

Directional Influences

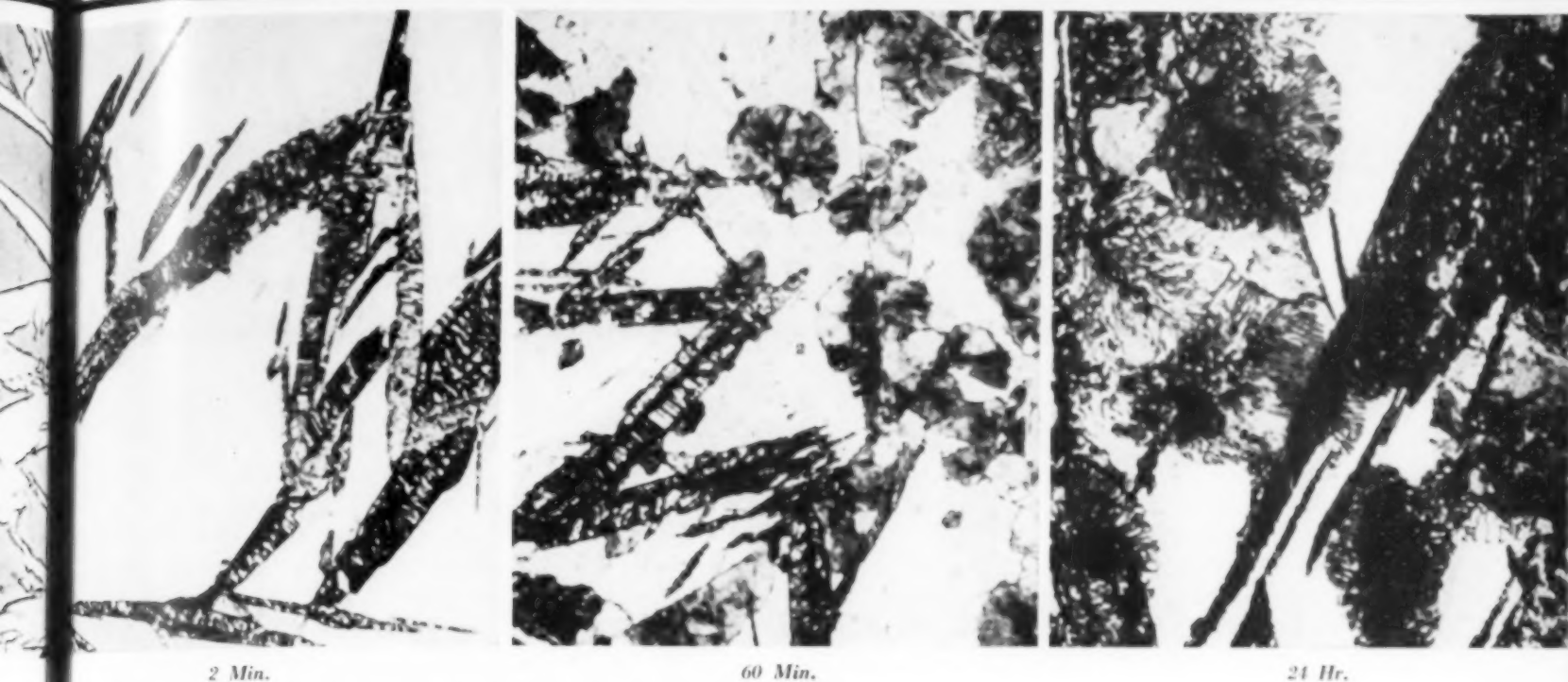
Possibly this agglomeration movement is not entirely haphazard. C. H. Desch has advanced the view that molecules of cementite are deposited as submicroscopic sheets in tempered martensite parallel to the {011} planes of the body-centered cubic iron. The existence of oriented carbide platelets might explain the dark, mottled etching effects of some martensites and the mid-rib observed in the needles of martensite in high carbon steel. At low tempering temperatures the atomic planes have powerful directing forces for platelet production, while at higher temperatures, where surface tension forces are dominating, either additional precipitation or the coalescence of the low temperature



Not Reheated



Approximate Relationship Between Cooling Rate and the Temperature at Which Austenite Begins to Transform. If the quenching curve of the slowest cooling particle in the steel mass passes to the left or is faster than the critical quenching rate, then the structure is hardened throughout and consists (until it is tempered) of martensite and retained austenite



2 Min.

60 Min.

24 Hr.

ure of Carbon Steel, Quenched and Immersed in Liquid Air and Then Tempered
ndicated Times at 975° F. Martensite needles precipitate carbides very rapidly.
ed austenite transforms to fine pearlite very slowly. (Courtesy of E. C. Bain)

sheets or particles results in the familiar granular cementite.

Bain's experiments immediately suggest that the classical concept that austenite disintegrates into a succession of the so-called transition products — martensite, troostite, sorbite, and pearlite — is no longer tenable. It would seem that at elevated temperatures austenite is converted directly to coarse lamellar pearlite, and in a slightly lower range to nodules of very fine pearlite lamellae, and that martensite is not the universal first product. An investigation of arrested transformations indicated that martensite is formed *only* at a low temperature (below about 300° F.).

Why austenite can transform in two very different ways is clearly evident if it is recalled that two reactions are involved, one is the allotropic change in iron and the other is precipitation of carbon, or, in other words, (a) martensitization and (b) martensite destruction. If the latter occurs at a considerably higher rate than the former, then conversion into pearlite without even the transient production of martensite is possible. A study of these rates at 975° F. is contained in the four photomicrographs from E. C. Bain's Howe Memorial Lecture (A.I.M.E., Iron and Steel Division, 1932), wherein austenite and martensite of the same composition were obtained side by side in a single specimen and observed to react at the same temperature to form ferrite and cementite.

The sample was first quenched to retain austenite, then immersed in liquid air to convert susceptible areas to freshly quenched martensite, and finally reheated to 975° F. (525° C.) for various periods. Martensite and austenite before reheating are represented in the first view. After only two minutes at 975° F. (second photo) the martensite had precipitated carbides of such dimensions that long additional time resulted in little coalescence. After one hour at 975° F., a portion of austenite had commenced to change; after 24 hr. the major part had transformed to fine, nodular, lamellar pearlite. In both freshly quenched and aged martensite, the rate of martensitic destruction was determined to be many thousand times more rapid than the velocity of austenite decomposition. This proves that by no mechanism could martensite occur as an intermediate stage, and that pearlite is the direct product of austenite at that temperature.

Arrests During Quenching

These conclusions have recently been confirmed by an ingenious application of thermal methods by H. Esser and W. Eilender in Germany. Previously many incorrect deductions have been made from thermal data because of the experimental difficulties encountered in the unusually rapid cooling rates. Esser and Eilender measured cooling rates of several thousand degrees per second by (Continued on page 68)

An extended abstract of a paper for the Chicago Convention wherein the authors point out inconsistencies in present use of the term troostite. They recommend calling tempered martensite "sorbite." An unnamed acicular constituent in quenched carbon steel is also described

On Naming The Aggregate Constituents In Steel

STUDY of the heat treatment of steel has been facilitated by coining a number of words to designate single constituents and conglomerates. It would be equivalent to holding a low opinion, indeed, of the advance in science to expect that the names assigned are now as aptly applied as they were at the close of the nineteenth century. Indeed, it is rather to be expected that the application of improved research tools in a comparatively new field might result in the revision of a large number of word definitions.

Of the many names for the structural states in steel, cementite, austenite, ferrite, martensite, ledeburite, and osmondite are now unquestionably so defined as to be acceptable to nearly all metallurgists. There remain three terms which are in daily use but upon which there seems to be no close agreement as to precise meaning: Sorbite, troostite, and pearlite. At present the chief shortcomings in definition have to do with (a) overlapping domains of words; (b) inherently different structures covered by one word, which incorrectly implies a close similarity; and (c) certain implications which are not in accord with observation.

By J. R. Vilella,
G. E. Guellich
and E. C. Bain
United States Steel Corporation

Pearlite

When Sorby's polishing and simultaneous etching of a specimen had served to reveal to his microscope the alternate layers of ferrite and carbide, the reason for the pearly iridescent appearance of the annealed steel surface was at once explained. Howe gave to "Sorby's pearly constituent" the new name pearlite — originally "pearlyte." The name would not have been applied to any but a lamellar structure for only by these layers in relief acting as a grating in decomposing light was the pearly appearance produced. This circumstance would appear to be ample reason for excluding any but the lamellar structures from the category of pearlite.

If, now, these lamellae of pearlite were always clearly observed by *any* metallographer with *any* microscope and with *any* polishing and etching technique, no ambiguity could have arisen, but unfortunately this is not true. The lamellae are not always equally spaced; on the contrary, in any certain steel the mean spacing of the carbide plates is a function of the precise temperature at which the austenite transformed to pearlite. The more rapidly the austenite is cooled, the greater will be the undercooling prior to transformation and, in turn, the thinner, and more numerous, the pearlitic (ferrite and carbide) lamellae. This is illustrated in the first series of photomicrographs, Fig. 2 to 6. In the finer pearlites the separate lamellae are well resolved only where they make an acute angle with

the polished surface, and then are seen only in a good modern microscope. Consistency, however, would indicate that pearlite should include not only the coarse but the finer lamellar structures, unresolvable to the early observers because of their inferior equipment and technique.

[The editor here interposes a remark that the structures illustrated in this paper are best produced by quenching a small rod of carbon steel in a molten bath at the desired temperature and holding it there a measured time before its removal for quick cooling to room temperature. In this way there is a very small difference in temperature at edge and center of the specimen at any instant, and the rate and nature of the ensuing reaction can be determined with precision. The mechanism of the transformation of austenite to pearlite at temperatures somewhat below the critical (in this case 1300° F.) is shown in the second series of micros on page 30, Fig. 8 to 12. We now resume with the authors' words.]

A grain of austenite may transform by going over to lamellar ferrite and carbide upon a dozen different fronts. As soon as the pearlite is formed, its lamellae remain quite definitely unchanged for hours, or days, even when the temperature of the transformation is maintained; the coarseness of the lamellae is established, once and for all, by the temperature of the transforming austenite for any particular composition and grain size. Coarse lamellar pearlite never forms from nodules of fine lamellae.

The Nodular Constituent

But how about the lower limit of fineness? The usual means of depressing the temperature of actual transformation and hence of reducing the spacing of the pearlite lamellae is that of cooling a steel more and more rapidly. Finally, when the so-called critical cooling rate is just reached (provided the coolant is below about 200° F.) the austenite transforms, at least in part, to characteristic martensite. At these rates of cooling near the critical the martensite will be mixed with a quick etching product which transformed at 950 to 1000° F. The last mentioned material certainly represents the normal limit of fineness of carbide lamellae. It is frequently called "nodular troostite," but the microscope shows that there are lamellae present in it and it therefore fulfills the requirements for pearlite. (See Lucas' excellent micrographs in February METAL PROGRESS.) In the authors' laboratory and in the publications therefrom the words "fine pearlite" have been used exclusively to designate this material.

In the strictest sense, pearlite is always nodular, in that it forms by the gradual encroachment upon the remaining austenite grain of several nodules spreading from a number of nuclei located usually in the grain boundary. If the temperature of actual transformation is lower, the nodular aspect is more pronounced, merely because the single "colonies" are more rosette-

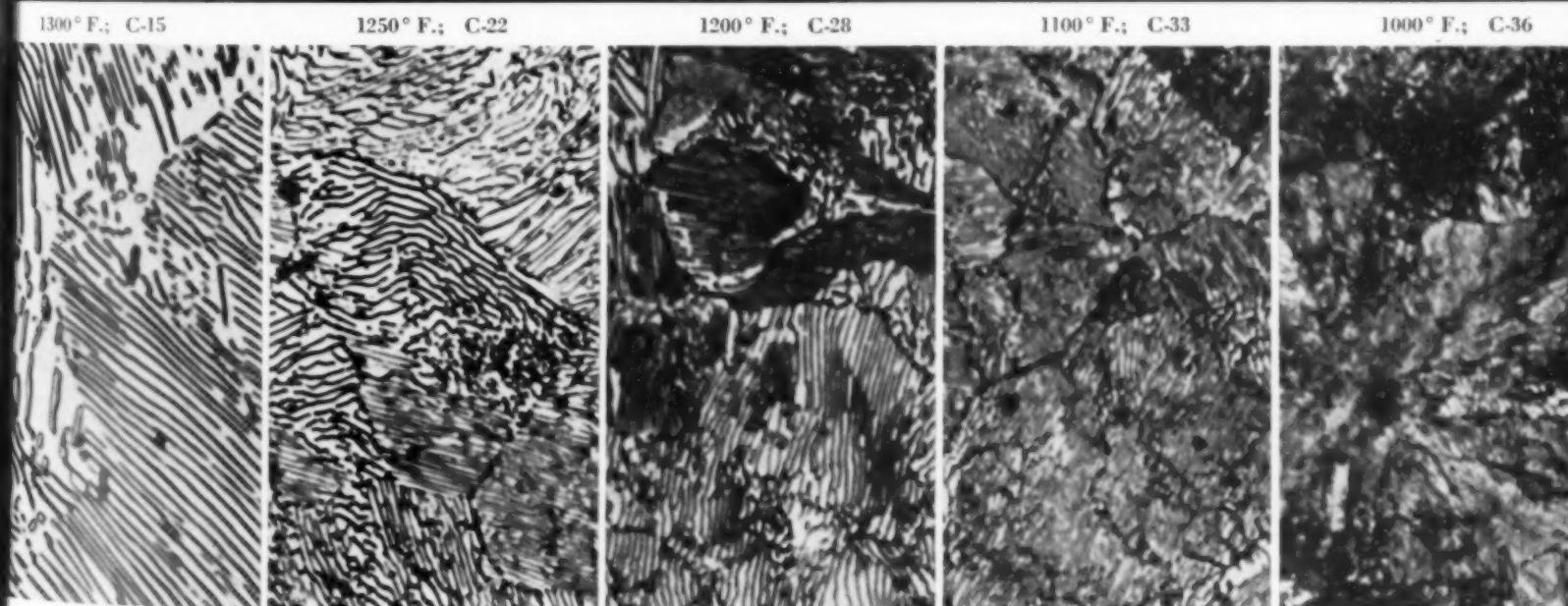


Fig. 2 to 6 — Pearlite in 0.78% Carbon Steel, All at 3000 Magnifications. Lamellar spacing and hardness depend upon temperature at which austenite transformed to pearlite, as noted above each micro

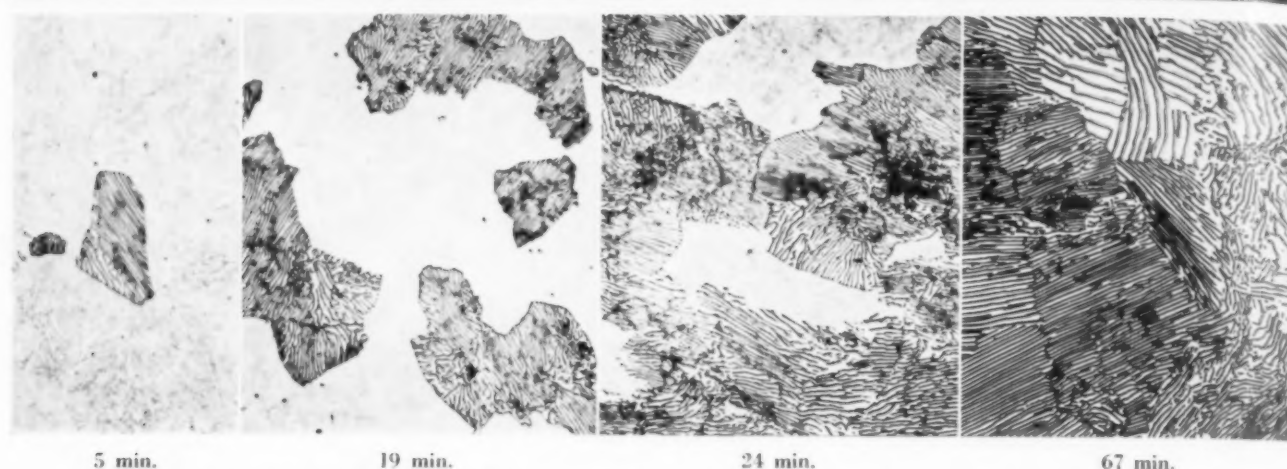


Fig. 8 to 12 — Mechanism of Pearlite Reaction, and Decreasing Amount of Austenite After Increasing Time at 1300° F. Note that lamellar spacing does not change with time. 600X

like in contour, and usually grow out rather uniformly from the austenitic grain boundary in all directions into both grains. [The platelets or lamellae grow by edge extension.]

If it can be prevented, the definition of pearlite should not depend upon the progress of optics or the skill of the observer. Since it is apparent that the constituent heretofore designated as nodular troostite is fine pearlite which transforms directly from austenite at or near the minimum temperature at which such direct transformation is possible (namely 950° F. or slightly higher) the following is suggested as a definition:

"Pearlite is the *lamellar* aggregate of ferrite and carbide resulting from the direct transformation of austenite at temperatures (usually above about 950° F. for carbon steels) at which the diffusivity of carbon is sufficient to permit the simultaneous formation of ferrite and carbide rather than an acicular structure, however transient, of ferrite supersaturated with respect to carbon."

Spheroidization

In heterogeneous systems the reduction of interface area results in a slight but definite evolution of heat and represents a trend toward a state of lower energy and greater stability. This necessitates a mild driving force toward particle growth, which reduces surface area. Consequently, at temperatures near A', the carbide in carbon steels forms rough spheroids which may be resolved by a microscope at as low a magnification as 100. A *coarse* lamellar structure will show no tendency to spheroidize at a temperature

which, when employed for tempering martensite, produces only a *fine* spheroidal structure, for such a spheroidization would imply an *increase* in interface area. Indeed, very coarse lamellar pearlite coalesces to spheroids very slowly at any temperature.

This matter is introduced here as a background for a consideration of the naming of the coarser spheroidized structure produced commercially from fine pearlite in the interest of maximum softness.

Fig. 14 — Simultaneous Formation of Lamellar and Acicular Products of Austenite Transformation. 1000X. Specimen was quenched in hot bath at 1000° F. and later removed to cold brine. White areas represent austenite (now untempered martensite). Black splotches are quick etching nodules of fine pearlite. Unnamed acicular constituent forms the striated gray areas.



The sound logic involved in the application of the word pearlite to pearly (that is, lamellar) structures at once urges the exclusion of any spheroidized structure from this category. Such spheroidized structures might well have been named "spheroidite," but one hesitates to think of adding yet another name to a list already too long. Perhaps "spheroidized cementite" will suffice for the present.

The Acicular Constituents

It appears from various recently published studies that there are two, and only two, *easily* distinguishable mechanisms for the transformation of austenite, and that they relate, for any

martensite to a very few millionths of a second.

In carbon steels the decomposition of the austenite proceeds according to the pearlite reaction at temperatures down to about 950 or 1000° F. and at all temperatures below this point according to the acicular reaction. Indeed, there is a narrow range of temperature at which both reactions proceed at so nearly the same statistical rate that both products may be seen in the same specimen, as in Fig. 14.

When, by virtue of rapid quenching and the resultant extreme undercooling, the acicular reaction occurs below some 300° F., the product, if immediately further cooled, is generally the hard, highly supersaturated, strained ferrite (that is, martensite) in which, probably, the carbide par-

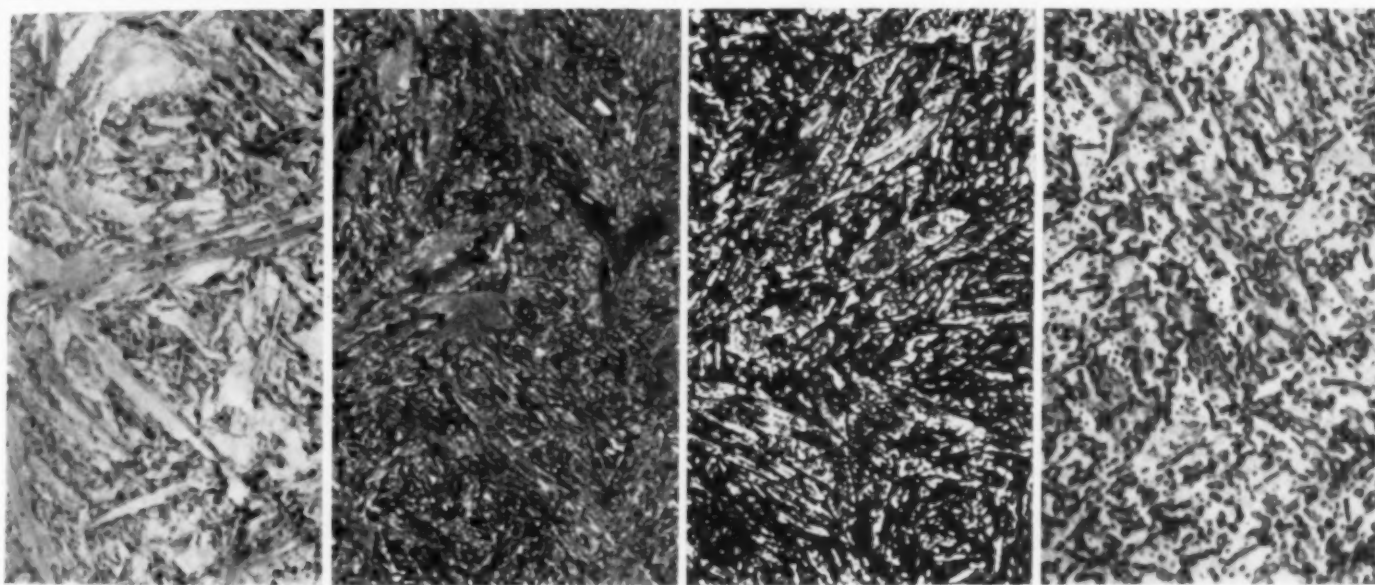


Fig. 15 — Martensite

Fig. 16 — 2 hr. at 445° F.

Fig. 18 — 2 hr. at 840° F.

Fig. 17 — 5 min. at 1200° F. (Sorbite)

Fig. 15 to 18 — Typical Martensite in Eutectoid Carbon Steel and Its Appearance After Tempering. All 2000X

particular steel, to the actual temperature of the particular portion of austenite undergoing transformation:

1. The Pearlite Reaction. This has been sufficiently described above.

2. The Acicular Reaction. This is the successive, abrupt formation of flat plates of supersaturated ferrite along certain crystallographic planes of the austenite grains. This supersaturated ferrite begins at once to reject carbide particles (not lamellae) at a rate depending upon temperature. In effect, this is the *acicular mode* of transformation, even though the temperature be such as to limit the actual life of the quasi-

ticle precipitation has not occurred to any considerable extent. This material does not darken rapidly during ordinary etching for microscopic examination, and is illustrated in Fig. 15. A reheating brings about a shower of carbide particles and the products are *now* known as troostite or sorbite depending upon the degree of coalescence. The structures resulting from such reheating are illustrated in Fig. 16, 18, and 17. All attempts to produce a lamellar distribution of ferrite and carbide by tempering martensite have so far failed.

The microscopic appearance of the softer acicular products formed directly from austenite

at temperatures between 900 and 300° F. resembles tempered martensite, although experienced metallographists are generally able to distinguish between the two acicular forms with but little difficulty.

The characteristic difference in the structure is illustrated in Fig. 21 and 22 and the accompanying sketches just below. At the higher temperature the formation of nuclei is slow and restricted and growth is rapid in a favored direction from such nuclei. The result is transformed material in fairly large masses. At the lower temperature range, nucleation is profuse but transformation is slow and occurs along several geometric directions; the result is a residue of austenite shot through with spines of transformed material.

The particular acicular structure formed at still lower temperatures (in the vicinity of 300° F. or lower), in which any carbide precipitation is in so fine a colloidal state as to be largely speculative, has been named martensite and no reasonable ground exists for criticism. The softer acicular structures are formed in one of two ways — (a) by tempering martensite, and (b) by direct austenitic transformation at temperatures usually between about 900 and 300° F. (The latter is as yet only rarely carried out commercially and the product may at some later time require a name.) At the moment the tempered martensites are spoken of as either troostite or sorbite, the less markedly softened structures being called troostite and the more thoroughly softened martensite being termed sorbite.

Troostite

The 1912 Congress evolved a consistent definition for an aggregate of this name, troostite:

"In the transformation of austenite, the stage following martensite and preceding sorbite (and osmondite if this stage is recognized)." This is a definition which, if the term persists, may well be preserved, but unfortunately for the present student, equipped with a good modern microscope, the Congress too generously provided two methods of developing the structure, one of which is incompatible with the definition. To quote the 1912 document:

"It (troostite) arises either on reheating hardened (i.e., martensite) steel to slightly below 400° C., or on cooling through the transformation range at an intermediate rate, e.g., in small pieces of steel quenched in oil, . . . or in the middle of larger pieces quenched in water from above

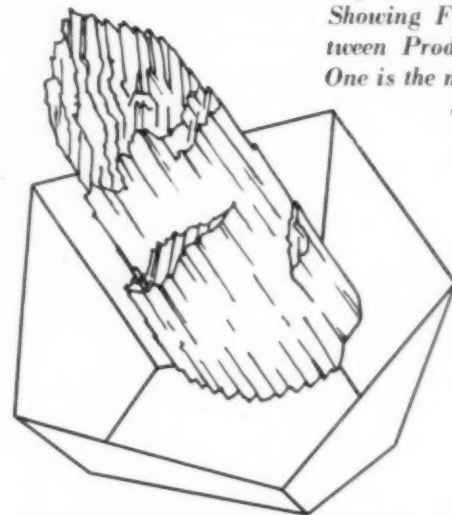


Fig. 21 and 22 — Micros and Sketches Showing Fundamental Difference between Products of Acicular Reaction. One is the more massive transformation of a crystal of austenite into troostite at 1000° F., near the

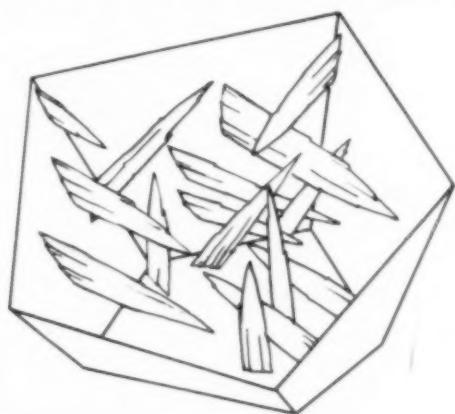
the transformation range." It is further stated that it is habitually associated with martensite which identifies the product of the second method of formation with the dark-etching nodules which we now know to be fine pearlite.

Considering now the first method prescribed for the formation of troostite, one finds that the structure is very different as illustrated in Fig. 18, which reveals a particle precipitation structure with sufficient right-line markings to prove its acicular origin. It would appear necessary to exclude the lamellar structure of nodular origin which formed by the direct pearlite reaction at A' from the category of troostite and to consider only its application to tempered martensite — in which case, one may employ the 1912 definition except perhaps for the first five words which might be replaced with a new clause and read:

"Troostite — In the gradual tempering of the freshly hardened steel, the stage following mar-



upper temperature limit for this mode of reaction. The other is acicular structure formed by incompletely reacted eutectoid carbon steel at 550° F., characteristic of transformation near the temperature range where austenite transforms into martensite



tensite and preceding sorbite." It arises on reheating martensite in carbon steel up to 750° F. At or about a 750° F. temper, the structure has maximum solubility in dilute H_2SO_4 , and has been called "osmondite."

In this connection, it appears that Arnold, one of the participants of the 1912 Congress, realized the lamellar nature of all the direct higher temperature transformation products of austenite (that is, the products of the A' transformation) for he counselled the use of "troostitic pearlite" for the finest and hardest direct products and "sorbitic pearlite" for the coarser and somewhat softer structures. Curiously enough, his proposals were rejected because "this is contrary to general usage, which restricts pearlite to microscopically resolvable masses." But the very structures under discussion are today resolvable, or resolvable, and by the same good reasoning should be called pearlite!

Sorbite

The 1912 definition of sorbite reads: that structure "in the transformation following troostite, and osmondite if the stage is recognized, and preceding pearlite."

This definition is thoroughly consistent in itself if one write "spheroidized pearlite" [or perhaps better "spheroidized cementite"] in place of pearlite. This might well have been done in the 1912 definition because pearlite was recognized as lamellar even then, and simple experiment shows that no reheating of troostite or sorbite can ever develop coarser lamellar structures, but instead merely causes spheroidization.

These observations persuade the writers that neither of the words troostite or sorbite need include the lamellar structures formed by the pearlite reaction. It is even questionable whether two names are needed for the tempered martensites. This series, from the slightly reheated aggregates to the softer products of high reheating temperature, is completely continuous and the application of different words tends to obscure this continuity, which is perhaps the most important feature of precipitation phenomena in metals. Whether or not different stages of coalescence are better distinguished by different names is largely a matter of individual taste. Those who incline to such names may point to such a series as dust, sand, gravel, stones, boulders, and there is no fitting rejoinder. For our part, we feel that the dropping of the word troostite would clearly cause no great hardship and at the same time its use permits the possibility of ambiguity unless it be definitely assigned to some arbitrarily limited range of a continuous series.


In conclusion, the authors suggest that (1) pearlite apply to all lamellar structures in steel formed by direct nodular transformation and (2) sorbite apply only to tempered martensite.

[This leaves as an unnamed constituent the product of direct transformation of austenite between 1000° F., the low limit for fine pearlite, and 300° F., the high limit for martensite. It is a dark etching, acicular aggregate considerably more uniformly stratified and in larger masses than tempered martensite. Its hardness and coalescence are dependent upon the transformation temperature. Its mechanical properties — toughness — are quite superior to those of martensite tempered to equivalent hardness. It is seldom seen in commercial steel, being the product of a heat treatment analogous to patenting of small wire.]

Dr. Honda, honorary member of American Society for Metals, supports the classical view that martensite forms momentarily during the transformation of austenite to pearlite, and therefore sees no reason for distinguishing between nodular troostite and martensite-troostite

Austenite → Martensite → Pearlite

The Classical View

 METAL PROGRESS, last March, contained an important letter from V. Koselev and F. Poboril of the Skoda Works, Pilzen, Czechoslovakia, commenting on the nomenclature of the various structures in heat treated, hypo-eutectoid steels. They proposed that the observed microstructures could be adequately explained on the assumption that the gamma phase (austenite) changes directly into "(a) normal or coarse pearlite at A_1 , (b) medium pearlite at the A_1 or the A_1' transformation, (c) fine pearlite or troostite at the A_1' transformation, and (d) martensite at the A_1'' transformation." They also assert that the structures developing from martensite when it is tempered differ one from another only in the fineness of cementite dispersion and "suggest, therefore, that tempered martensite should be called fine sorbite or coarse sorbite, according to its nature. Only coarsely coagulated sorbite should be termed 'spheroidized.'"

These assertions arise from the implied assumption that there are two kinds of troostite, different in nature: (a) The quickly etching constituent appearing after mildly tempering a quenched and fully hardened steel, and (b) the dark etching, nodular constituent appearing with martensite in an incompletely quenched steel before it is tempered.

By Kotaro Honda
President
Tohoku Imperial University
Sendai, Japan

According to the view of the present writer, these two structures do not differ essentially from each other and consequently there is no need to distinguish them.

According to my theory accounting for the transformations in carbon steel (as developed in various contributions to the *Science Reports* of Tohoku Imperial University, especially 1919, p. 181; 1922, p. 487; 1925, p. 165; and 1929, p. 503, and summarized in *Transactions, A.S.S.T.*, July, 1929), the A_1 transformation consists, in its mechanism, of two changes going on one after another in an immediate succession. That is to say, the A_1 transformation is identically equal to two stepped changes: Gamma iron with carbon in solution changes to alpha iron with carbon in solution and the latter then changes into an aggregate of alpha iron and cementite. Or, expressed in terms of microstructures

austenite → martensite → pearlite

[Here it might be pointed out by the editor that Dr. Honda uses the word "pearlite" in the above equation in its generic sense meaning "a mechanical mixture of iron and cementite," irrespective of the state of aggregation of these two constituents, whether colloidal, fine or coarse globular, or lamellar. In other writings he also uses the word in the specific sense of a fine lamellar structure with pearly sheen.]

In case the steel specimen is cooled slowly, the above two changes or steps take place one after another immediately, so that the result is

A_1 transformation — austenite → pearlite

but in the case of rapid cooling, the first step (austenite \rightarrow martensite) is greatly retarded and begins to take place at 200 to 300° C. (400 to 575° F.). By the time this first change is completed the specimen is at room temperature, and hence the second change or step (martensite \rightarrow pearlite) is arrested because this change involves the diffusion of carbon atoms through iron, and this is resisted by the great viscosity of the specimen at the low temperature. We therefore obtain martensite at room temperature.

If the rate of cooling is a little less than the above case, which gives a perfect hardening to full martensitic structure, the first step or change begins at a higher temperature (about 550° C. or 1025° F.) and when this change is completed, the specimen is still at some higher temperature than room temperature; hence a portion of the specimen, which underwent the change to martensite at the high temperature, makes the second step of the change and forms nodular troostite. This structure indicates that the breaking up of martensite begins to take place at some points at the grain boundary as centers, and spreads forward radially.

Hence even the nodular structure is formed from the decomposition of martensite, but not

directly from austenite in the strict sense of the word, the life as martensite being very short.

That portion of the specimen now under discussion, which does not undergo the first step of the change above 500° C., is so far retarded that the same change begins at 300° C. or a lower temperature, the result being martensite. The reason why the change from austenite to martensite cannot take place in the range of 500 to 300° has already been explained by the present writer in *Science Reports*, 1922, p. 105.

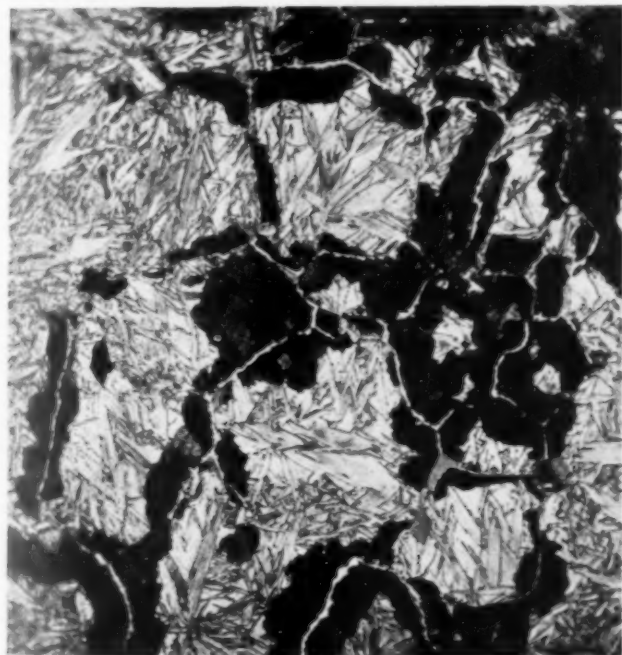
Thus there is no essential difference between (a) nodular troostite and (b) ordinary troostite obtained by tempering martensite; both of them are the decomposition products of martensite, the only difference being the life-period of martensite. That is to say, in the case of the nodular structure the life-period of martensite is very short (owing to the high temperature of exposure) and in the other case it is comparatively long. Hence it is better to call these two troostites by the same name, as has been usual.

From the physical point of view, pearlite, sorbite, and troostite are all the same phase—consisting of a mixture of ferrite and cementite—the difference being the degree of fineness of cementite particles and/or lamellae. Hence it would theoretically be more correct to use a single generic term to denote them, such as coarse pearlite, medium pearlite, and fine pearlite, as has been done by E. C. Bain. However, the generic term “pearlite” is not suitable, because this means a pearl-like structure and is derived from the appearance or tint of very fine lamellar structure, as seen in white light under a microscope. So the original terms sorbite and troostite are preferably to be preserved.

The spheroidization of lamellar cementite by a prolonged heating is the effect of the surface tension of cementite. Surface tension tends to minimize the surface energy of a phase and therefore to round up the cementite grains. Thus lamellar cementite is less stable than spheroidal cementite, and hence lamellar cementite can never be formed from globules.

Since troostite is a dispersed system, in which cementite is suspended in iron as very fine colloid-like particles, lamellar cementites never appear in tempered martensite.

Considering these facts in detail, we cannot agree with the proposal made by Koselev and Poboril regarding nomenclature of the microstructures. It is desirable that the original terms should be used to determine the degree of fineness of cementite particles.



Hardened Hyper-Eutectoid Steel at 500 Diameters (J. R. Vilella). Dr. Honda holds that the dark etching constituent should be called troostite, believing that its origin and essential structure are the same as that formed from the acicular martensite grain centers after moderate tempering

Best structure for wire drawing is had by quenching high carbon steel in molten lead. It is commonly called sorbite, but is really fine pearlite, whereas true sorbite (a quenched and tempered structure) can hardly be drawn

Difference Between Structures Shown By Cold Working

THE MICRO-CONSTITUENT commonly termed "troostite" has been defined both (a) as a stage in the transformation of austenite, following martensite and preceding sorbite, and (b) as a constituent of hardened or hardened and tempered steels. Sauveur, in elaborating the first definition, states "In order to produce troostite on cooling steel from above its critical range, it is necessary that the cooling through the range should be so regulated to allow it to form and at the same time prevent its further transformation (into sorbite and pearlite)." He further states "Troostite may also be produced by tempering (i.e., reheating below the critical range) austenitic and martensitic steels." From this, the conclusion can readily be drawn that the transformation of austenite, which takes place on cooling from above the critical range, produces the same constituents at different stages as does the reheating of quenched austenite or martensite during tempering; that martensite, troostite, sorbite and pearlite are the transformation stages in both cases and that each structure succeeds the one previous in the order named as the austenite → pearlite transformation proceeds.

Lucas has shown in an article in Bell System

Technical Journal, Vol. IX, p. 105, that the nodular structure termed troostite, often found associated with martensite in quenched steels can, by the use of higher magnifications, be resolved into fine pearlite. He also offers evidence which indicates that the nodular structure is formed directly from austenite. Going further in an article in METAL PROGRESS in February, he has termed "troostite" the structure of fine pearlite observed in an air cooled, hot rolled rod, $\frac{1}{2}$ in. diameter, and of slightly hypo-eutectoid composition. Bain has shown in several recent papers that the fineness of pearlite increases as the temperature at which the A_r' transformation takes place is lowered and that, at a point just above the position of the A_r' that will form an acicular structure, extremely fine pearlite is produced. Obviously this requires clarification to most metallurgists for, if the nodular structure found associated with martensite is fine pearlite and if, as shown by Bain, fine pearlite is produced by rapid cooling to a certain sub-critical temperature, the question as to the existence of "troostite" and "sorbite" as constituents of steel cooled at intermediate rates from above the critical range can rightfully be raised.

The primary constituents, which result from quenching or fast cooling, form under conditions that differ from those under which the tempering constituents are formed—the prime difference being the time of formation. The presence of fine pearlite in the nodular structure associated with martensite, as shown in the view on page

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35, indicates that stratification takes place immediately when the transformation occurs at a temperature slightly above that required to form martensite. On the other hand, a study of the structure termed troostite and produced by tempering indicates that, in this case, the carbide precipitation is not stratified to any great extent, but rather consists of fine particles, the size of which increases as the tempering temperature is raised, until at about 650° C. (1200° F.) the structure will consist of globules of cementite in a matrix of ferrite. At no time does the tempering of martensite produce pearlite.

A study of the structure from which high carbon wire is drawn may be employed as evidence of the dissimilarity existing between the so-called troostite of the quenched steel and the troostite of the hardened and tempered steel.

The prime requisites of high carbon steel to be drawn into wire are (a) ductility to permit deformation and (b) uniformity of the constituents to insure uniformity of strain distribution. Fine pearlite, because of the ductility afforded by the thin cementite plates and alternate ferrite plates, is the most suitable structure from which to draw high carbon steel wire. The patenting treatment develops this fine pearlite in steel to be drawn; this consists of a heating above the critical and a fairly rapid cooling, using either air or a lead bath as a coolant. The rate

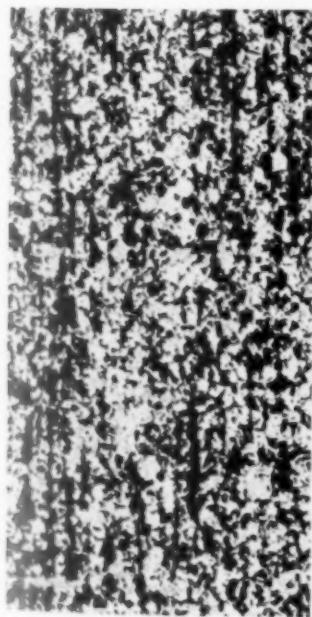
of cooling must be fast enough to produce fine pearlite yet slow enough to prevent the formation of any particles of martensite.

Unsatisfactory Patented Structure

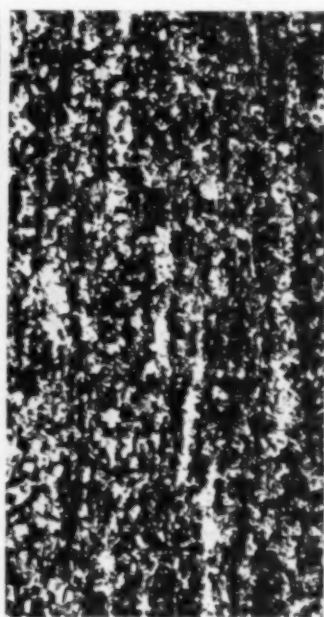
It is not uncommon, however, in the patenting of high carbon steel wire of small section to find some martensite present. This is due, in the air patenting, to cooling from too high a temperature or, in the lead patenting, to too cool a lead bath. By lowering the temperature from which the air cooling begins or by raising the temperature of the lead the amount of martensite present can be reduced or eliminated from the structure. Wire which is patented in a manner that will cause the $A_{r'}$ transformation to take place just above the point at which any martensite is formed, is in an ideal condition for wire drawing. This elimination of martensite from the structure and the development of fine pearlite by altering the temperature, as described above, is shown in the first group of micros.

Properly patented wire, consisting of fine pearlite, will not exceed Rockwell C-35 in hardness (when a steel of slightly hypo-eutectoid composition is used) and may be reduced 45% in cross sectional area in one draft, or as much as 95% when a number of drafts are employed. The figure on page 38, taken at 2000 \times , shows the

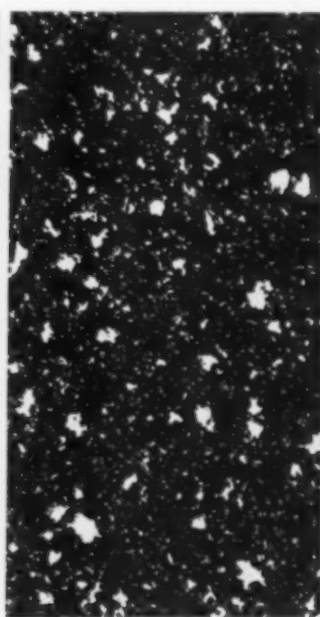
Replacement of Martensite by Ferrite and Fine Pearlite in Structure of Patented Wire Rod by Altering the Cooling Rate. All at 100 \times



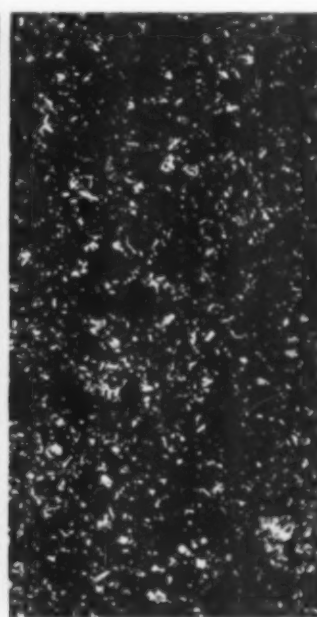
Very fast gives large amount of martensite



Fast cooling gives less martensite



Still slower cooling gives nearly all fine pearlite

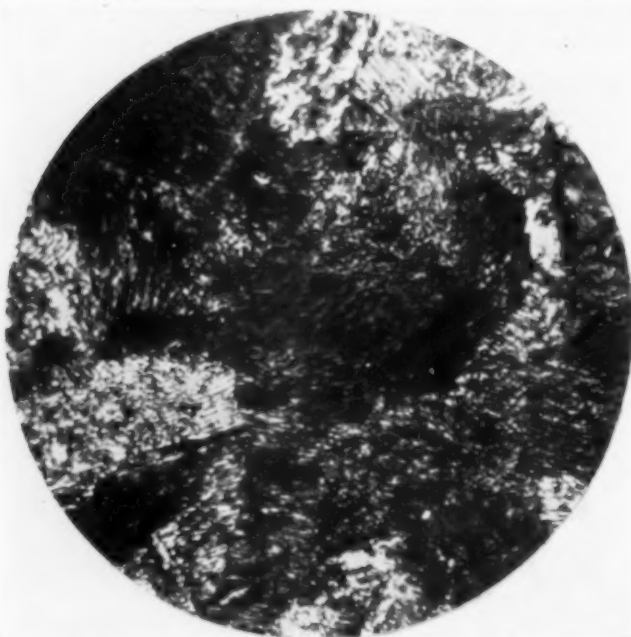


Fine pearlite structure suitable for wire drawing

type of structure which will permit this reduction. The flexibility of the thin plates of cementite permits freedom of movement, resulting in an equal distribution of cold work and the development of high strength combined with ductility which constitutes wire quality.

In contrast to this structure, which has frequently been termed troostite, the "troostite" of quenched and tempered steel wire of slightly hypo-eutectoid composition shown in the last view will differ both in physical properties and in ability to deform in wire drawing. The hardness of such tempered wire will vary, depending on the tempering temperature, from Rockwell C-52 down to C-45. Because of the hardness of this material, the amount of pressure required to effect any appreciable deformation will be greater than the strength of the wire being produced, and breakage will result. The ductility of the tempered steel rod may be increased by raising the tempering temperature to a point which makes cold working possible; however, the resulting structure, consisting of globules of cementite in a matrix of ferrite, although ductile, is not suitable for cold working because of the resistance of the globular cementite. This places the burden of deformation on the ferrite, producing an uneven distribution of strain which results in a brittle product after cold drawing.

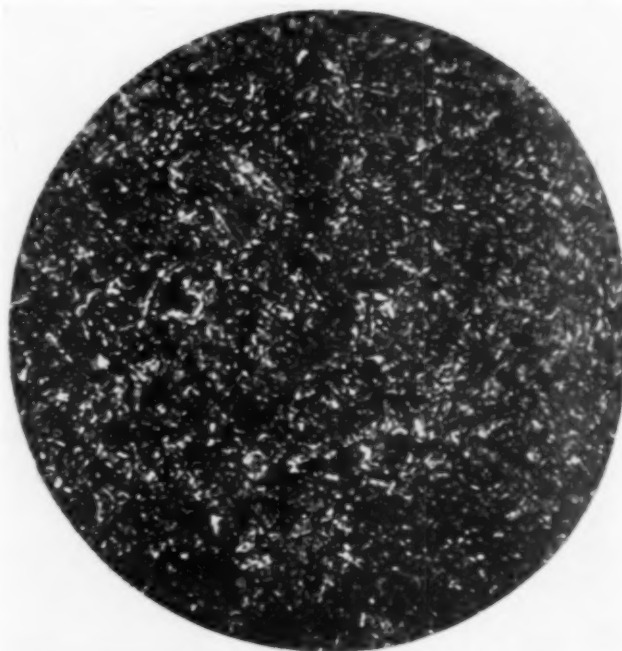
Cold drawing of fine pearlite (patented rod)



Structure of Fine Pearlite in Patented Rod for Drawing Wire of High Carbon Steel. Hardness Rockwell C-32. Magnification 2000X

may increase the tensile strength to 300,000 psi. and the drawn wire will still be ductile enough to stand wrapping around its own diameter. Contrast this with the fact that any reduction which might possibly be made on the quenched and tempered material while in the troostitic condition, is too light to be considered in the commercial manufacture of steel wire.

For years the desired structure in patenting has been commonly termed "sorbite" or "sorbite-pearlite." In the light of recent developments noted at the outset it would seem that this terminology should either be discarded or defined differently. A study of properly patented structures will show a preponderance of pearlite which can be resolved on high magnification (2000 X) and



Structure of Tempered Martensite From Spring Wire, Quenched and Tempered After Drawing. Rockwell C-48. 2000X

some which is unresolved, but in which tendencies toward stratification are noticeable.

The difference in physical characteristics between the two structures commonly termed troostite, indicates a marked dissimilarity of the ferrite and cementite arrangements and therefore a need of a better terminology. The use of the terms coarse pearlite, medium pearlite, fine pearlite and martensite seems sufficient to define the structures encountered in cooling steel at different rates from above its critical range, or by quenching steel in hot metal as in patenting.

Several letters indicate that American metallurgists have been distinguishing the so-called troostite formed during direct quenching from that appearing in tempered martensite, but no agreement exists as to preferred names for these constituents

Letters and Comment on Metallographic Structures in Steel

Howeite

A Name for Globular Cementite

■ ROLLA, Mo. — I am glad that my brief note in METAL PROGRESS, March, 1934, asking as a teacher for photomicrographs representative of pearlite, sorbite, and troostite has brought the matter of nomenclature to the fore. Evidently steel metallographers have also been disturbed about the names of borderline constituents.

Discussion has also brought out a term "globulite" for cementite globules in a ferrite matrix. I believe the terms "spheroidized cementite" and "divorced pearlite" for this structure are illogical. (To use them is like calling ice "frozen water," or water "melted ice.") True, these terms very clearly tell the past treatment of the alloy, but there is no advantage to using such long names. At the risk of complicating an already complicated situation, I offer the following definition:

Howeite: A structure resulting from a divorce anneal or spheroidizing treatment. A typical structure shows globular cementite embedded in a ferrite matrix.

The term was coined in honor of Henry Marion Howe, and has been used at the Missouri School of Mines and Metallurgy for the past ten years. It falls in line with austenite, martensite, troostite, sorbite, and pearlite.

CHARLES Y. CLAYTON

A Simplified Nomenclature

■ EAST PITTSBURGH, Pa. — The coinage and use of technical terms is justified solely by the possibility they provide of transmitting concepts quickly and with certainty from one person to another. If the terms are indefinitely defined, the advantage gained in using them is lost and argument tends to become futile. The efforts of Messrs. Poboril and Koselev towards improving this situation are therefore highly commendable whether or not one concurs fully with their terminology.

There is considerable practical value in generic terms to distinguish sharply between the structure of steel resulting from slow cooling (when only the $Ar_{3.2.1}$ transformation occurs) and that resulting from quenching, when only the Ar' transformation occurs. In the former case no serious objection appears to calling the high carbon areas pearlite. Modifying adjectives such as fine, lamellar, and spheroidized may, of course, be used for more specific description. Steels containing this constituent may then be identified as pearlitic, irrespective of cooling rate and composition.

The propriety of calling the hard product of quenching martensite has not been questioned, so fully hardened steels may be referred to without danger of misapprehension as martensitic. The use of the term sorbite to designate a product of tempering of martensite also has not been challenged. However, it would be well to main-

tain the distinction between spheroidized pearlite and coarse sorbite, though the microstructures be indistinguishable, because of the implication carried as to the type of treatment by which they were produced.

Our major difficulties are undoubtedly with the mixed structures, that is, those resulting from cooling rates at which both the Ar' and Ar" transformations occur. It is very important to use explicit terms here because the presence of a small amount of a soft constituent in martensite can make a great change in its mechanical properties.

The product of the Ar' transformation is usually called nodular or quenching troostite. From the work of Bain and Lucas, however, this constituent is simply a form of pearlite and should come under the same generic term. The writer has used the term fine pearlite to describe this constituent for several years and has been gratified with the simplicity it lends to presentations of the complex phenomena of heat treatment.

Troostite is also used to designate an early stage in the tempering of martensite. Since the properties of this material differ radically from those of pearlite, the dual use of the term troostite is highly objectionable. Its proper function is to describe a product of tempering martensite. The definition, of course, needs to be made more explicit, as can be done by precise statement of the boundaries between martensite and troostite and between troostite and sorbite. There are rather abrupt changes in certain properties on tempering martensite which may serve to define these boundaries more sharply than can be done with the microscope alone.

This viewpoint differs sharply from that of Poboril and Koselev only in usage of the term troostite. This difference is not in principle, but only in practicality. Apparently the prospects are excellent for an agreement among metallographists on a simple and clearly defined terminology for the micro-constituents of steel.

HOWARD SCOTT

Different Structures Deserve Individual Names

■ PHILADELPHIA, Pa. — I have long considered it unfortunate that the word troostite has been used both for the characteristic constituent that appears with martensite in quenched steel and for the other structure obtained after tempering the martensite.

In order to distinguish between the two, the

term "quenching troostite" was used for the first type and "tempering troostite" for the second type, but we in SKF Industries some years ago discontinued using "tempering troostite" and now use "tempered martensite" instead. We have not felt any particular need for retaining the word sorbite but believe it may be useful in describing structures obtained in tempering martensite.

We would suggest, therefore, that troostite be used only for the characteristic dark etching structure found adjacent to martensite in quenched steel and not resolved at 1000 magnification, and that sorbite be used for tempered martensite when the structure cannot be resolved at 1000 magnification. When cementite grains can be distinctly seen at 1000 magnification after tempering, the terms "fine granular pearlite" or "coarse granular pearlite" may be used, according to the appearance of the structure.

HAARON STYRI

Criticizing the Term "Spheroidized Pearlite"

■ COLUMBUS, Ohio — I have read with interest the letter from Messrs. Poboril and Koselev on nomenclature of microstructures in carbon steels printed in the March issue of METAL PROGRESS. I am in general agreement with the suggested terms and believe they are in line with recent work in this country.

The name "spheroidized pearlite" suggested by them still leaves something to be desired, because pearlite is definitely associated with the eutectoid composition, which is not necessarily present in the spheroidized structure produced by tempering a quenched specimen at high temperatures and usually for rather long periods of time. This microstructure does not necessarily have the eutectoid composition as a whole or in certain areas, and it has not been spheroidized from lamellar pearlite.

Unfortunately, there does not seem to be a name in the metallurgical literature which accurately designates this microstructure. Coining a new name has serious objections, in that the new name may not receive general acceptance, and at present we have a lot of names to remember — although apparently we are not going to have much further use for "Hardenite," "Osmondite," "Heynite," "eta, theta, and epsilon martensite," or "Boydenite."

OSCAR E. HARDER

Approximate Critical Temperatures for S.A.E. Steels

by M.J.R. Morris, R. Sergeson and G.W. Gable; Central Alloy Division, Republic Steel Corp.

In most instances found by examining microstructure of quenched 3/8-in. discs of 1-in. round, taken from furnace at 20°F. increments. Grain size of steel unknown. Rate of heating and cooling about same as in furnace-cooling for commercial annealing

Number	On Slow Heating			On Slow Cooling			Number	On Slow Heating			On Slow Cooling		
	Ac ₁	Ac ₂	Ac ₃	Ar ₃	Ar ₂	Ar ₁		Ac ₁	Ac ₂	Ac ₃	Ar ₃	Ar ₂	Ar ₁
Carbon Steels							Nickel-Chromium Steels						
1010	1350	1405	1605	1570	1400	1255	3115	1355	1400	1500	1470	1380	1240
1015	1355	1410	1585	1545	1395	1265	3120	1350	1400	1480	1455	1380	1230
X1015							3125	1350	1395	1465	1400	1380	1220
1020	1355	1410	1570	1535	1395	1260	3130	1345	1380	1460	1360		1220
X1020							3135	1340		1445	1300		1220
1025	1355	1405	1545	1515	1405	1255	3140	1355		1415	1295		1220
X1025							X3140	1350		1430	1300		1240
1030	1350	1405	1495	1465	1405	1250	3145	1355		1395	1295		1220
1035	1345		1475	1455	1395	1275	3150	1355		1380	1275		1215
1040	1340		1455	1415		1275	3215	1350	1410	1465	1415	1350	1240
X1040	1340		1450	1340		1270	3220	1350	1415	1460	1405	1355	1240
1045	1340		1450	1405		1275	3230	1340		1435	1395		1240
X1045	1335		1420	1330		1270	3240	1335		1425	1280		1240
1050	1340		1425	1390		1275	3245	1345		1400	1270		1225
X1050	1335		1400	1330		1270	3250	1340		1375	1255		1200
1055	1340		1425	1390		1275	3312	1330	1370	1435	1240		1160
X1055	1335		1400	1330		1270	3325	1335	1365	1400	1230		1160
1060	1340		1410	1370		1275	3330*	1320	1360	1380	1225		1145
1065	1340		1385	1345		1285	3335	1310		1360	1200		1100
X1065	1335		1380	1330		1280	3340	1290		1380	1180		1100
1070	1345		1370	1340		1280	3415	1330	1370	1425	1340	1300	1220
1075	1350		1365	1340		1280	3435	1290		1380	1200		1150
1080			1360	1285			3450	1290		1360	1200		1100
1085							Molybdenum Steels						
1090			1360	1285			4130	1395	1435	1485	1405	1395	1280
1095			1360	1290			X4130	1395	1435	1480	1405		1250
10150*			1355	1290			4135	1395	1440	1475	1380	1360	1280
Free Cutting Steels							4140	1380		1460	1370		1280
1112	1355	1410	1590	1545	1395	1265	4150	1365		1395	1355		1280
X1112							4340	1350		1425	875		725
1115							4345	1345		1415	875		725
1120	1355	1405	1550	1510	1400	1255	4615	1335	1400	1485	1400	1320	1200
X1314							4620	1335		1470	1390		1175
X1315	1345	1420	1520	1495	1370	1245	4640	1320		1430	1300		1125
X1330							4650*	1315		1410	1260		1125
X1335							4815	1300		1440	1310		800
X1340							4820	1300		1440	1260		760
Manganese Steels							Chromium Steels						
T1330	1325		1480	1340		1160	5120	1410	1460	1540	1470	1420	1295
T1335	1315		1460	1340		1165	5140	1370		1440	1245		1280
T1340	1315		1435	1310		1160	5150	1330		1420	1280		1220
T1345	1315		1410	1300		1160	52100	1340		1415	1315		1280
T1350	1310		1400	1255		1105	Chromium-Vanadium Steels						
T1360*	1305		1405	1200		1095	6115	1420	1460	1550	1450	1380	1300
Nickel Steels							6120	1410	1460	1545	1440	1380	1300
2015	1375	1475	1575	1450	1400	1215	6125	1400	1440	1490	1390	1360	1295
2115	1345	1455	1525	1475	1380	1195	6130	1390	1440	1485	1370	1340	1285
2315	1300	1350	1440	1350	1260	1100	6135	1390		1480	1370		1280
2320	1285	1345	1420	1235	1160	920	6140	1390		1455	1375		1295
2330	1275	1315	1400	1180		1050	6145	1390		1450	1375		1290
2335	1275		1375	1180		1050	6150	1385		1450	1375		1270
2340	1280		1360	1180		1060	6195	1370		1425	1360		1300
2345	1280		1350	1180		1060	Tungsten Steels						
2350	1280		1340	1180		1070	7260	1360		1430	1370		1310
2515	1250	1335	1420	1220	1140	825	Silicon-Manganese Steels						
2520*	1240	1340	1390	1175	1025	825	9255	1400		1500	1380		1320
							9260	1400		1500	1380		1315

* This number not in the official S.A.E. list



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Atmosphere Control In Radiant Tube Furnaces

A Catechism

QUESTION — What is the *theoretical* composition of the atmosphere within a fuel fired furnace?

ANSWER — When a fuel, such as city gas, natural gas, propane, butane or fuel oil, is burnt with its full complement of air to perfect combustion, the products of this reaction are carbon dioxide (CO_2), water vapor (H_2O), and nitrogen (N_2).

Q. — What is the *actual* composition of the atmosphere in practical operation of gas fired furnaces?

A. — In a correctly designed furnace with automatic proportioning equipment it is possible to control the atmosphere to secure perfect combustion; that is, there is no free oxygen (O_2) nor unburnt fuel.

Q. — What is the *usual* atmosphere maintained in a heat treating furnace, gas fired?

A. — It is usually preferred to maintain an atmosphere that is slightly reducing, that is, one containing no free oxygen but containing a slight amount of unburnt fuel.

Q. — What is the principal constituent of this unburnt fuel in a reducing atmosphere?

A. — The gas carbon monoxide (CO). It differs from carbon dioxide (CO_2) in that it is capable, at heat treating temperatures, of combining with more oxygen and it will do so if this oxygen comes as air infiltration, or is present as iron oxide or scale on the steel in the furnace.

Q. — How are furnace atmospheres usually designated?

A. — They are known as neutral, reducing, or oxidizing. A neutral atmosphere contains no unburnt fuel and no free oxygen. A reducing atmosphere contains some unburnt fuel and no free oxygen. An oxidizing atmosphere contains no unburnt fuel but some free oxygen.

Q. — What is the atmosphere in an electrically heated furnace?

A. — It is usually completely oxidizing; that is, it contains nothing but air, composed principally of free nitrogen (N_2) and free oxygen (O_2).

Q. — Can any other gases be found in the atmosphere of an electric furnace?

A. — This depends upon the work going through. If it be oily, this oil will consume the free oxygen of the air and if no air current is allowed to flow through the furnace chamber it is even possible after several hours of operation to have an atmosphere which is highly reducing.

Q. — What is the composition of the atmosphere in a muffle furnace?

A. — The same conditions apply in a muffle furnace as in an electric furnace, provided the muffle is made of heat resisting alloy and is impervious to the heating gases outside.

By W. M. Hepburn
and H. C. Weller
Surface Combustion Corp.
Toledo, Ohio

Q. — What is a radiant tube furnace?

A. — One which is heated by radiation from incandescent tubes, the latter made of heat resistant alloys and fired internally by diffusion of flame combustion. For a more complete answer see text at end of this catechism.

Q. — Can the temperature of a radiant tube furnace be controlled?

A. — The refinements of temperature control on existing types of furnaces are well known and the instruments for this purpose have been highly developed. Radiant tube furnaces are just as amenable to control by the same methods and the same instruments with just as close a degree of refinement.

Q. — What is the composition of the atmosphere in a radiant tube furnace?

A. — The same conditions apply in a radiant tube furnace as in an electric furnace, provided the tubes are impervious to the heating gases within.

Q. — What is the effect on hot steel at operating temperatures of the various constituents of furnace atmospheres?

A. — Oxygen (O_2), carbon dioxide (CO_2), and water vapor (H_2O) are all oxidizing or scale forming. They also decarburize steel. Carbon monoxide (CO) is reducing, that is, it will reduce iron oxide to metallic iron. It is also carburizing, that is, it will add carbon to steel.

Q. — What is a controlled atmosphere furnace?

A. — As the name implies, such a furnace is amenable to maintaining any desired or predetermined atmosphere necessary to prepare the metal or protect it.

Q. — Are such controlled atmosphere furnaces very new?

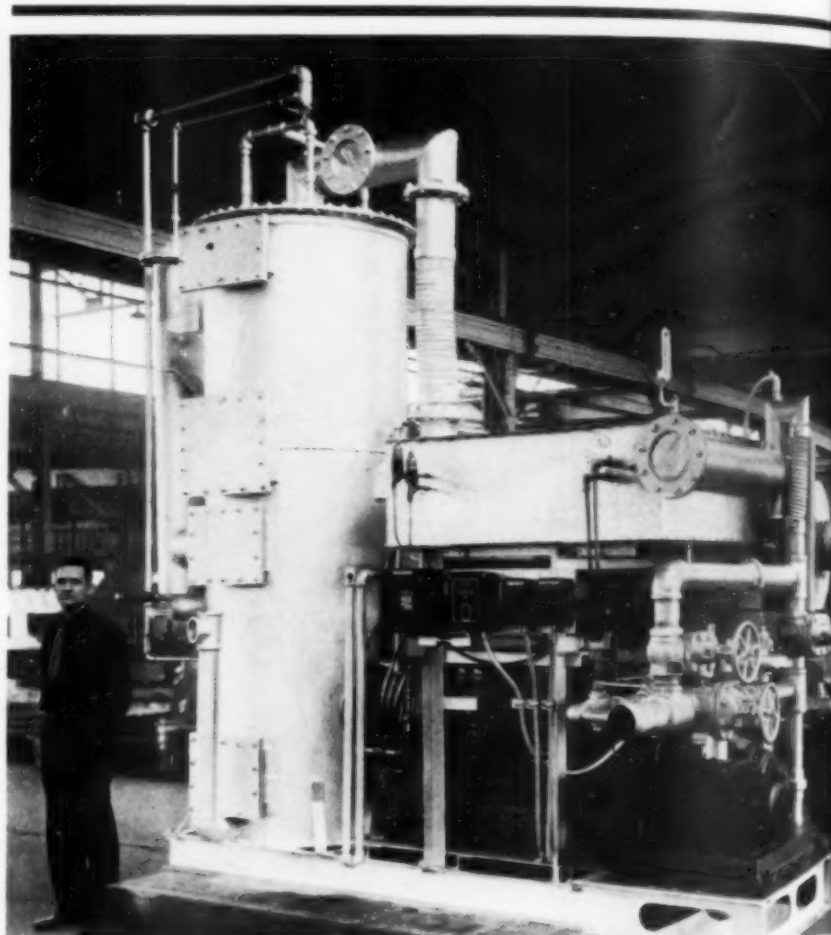
A. — They have been in use for many years. The first furnaces of this type were gas fired furnaces, properly designed, and equipped with automatic proportioning of air and gas for combustion. The atmosphere was that of the burnt gases within the furnace chamber (which excluded intrusion of air) and the proportioning equipment maintained this atmosphere with constant characteristics.

Q. — What was the surface condition of steel heat treated in such furnaces?

A. — It was very slightly oxidized.

Q. — Was there any decarburization in these furnaces?

A. — Most classes of steel, either high or



A Large "DX Gas" Production Unit, an Automatic Device for Partial Combustion of Gas and Its Proper Dehydration. Chemical characteristics of the output may be set so as to have the desired action with the hot metal in process, or to have no action.

low carbon, have been heat treated in such furnaces with perfectly satisfactory results. There may have been cases of slight surface decarburization, but generally speaking most of the steels so treated met the requirements of the job.

Q. — What are the new commercial conditions which necessitate an improvement in furnace equipment?

A. — Two things; first, the greater prevalence of alloy steels which are more susceptible to decarburization and second, the more stringent specifications for the finished articles.

Q. — Why can't present direct fired gas furnaces meet these requirements?

A. — Because if a fuel gas and air mixture were prepared that would neither scale nor decarburize these alloy steels, the mixture would not generate sufficient heat to act as a heating medium.

Q. — What type of furnace must be used to meet these atmospheric requirements?

A. — A furnace whose atmosphere is completely controllable must be heated indirectly (so that gases of combustion are not allowed to enter the heat treating chamber, and air is excluded) by flowing through the work chamber an atmosphere specially prepared in separate equipment.

Q. — What class of furnaces is capable of meeting these requirements?

A. — Radiant tube furnaces, full muffle furnaces and electric furnaces.

Q. — What conditions determine the choice of one or the other of these furnaces?

A. — Factors of engineering, design, cost of installation, and cost of operation.

Q. — What is the advantage of the radiant tube furnace?

A. — For heavy production furnaces it is easier to design and cheaper to build than the muffle furnace. Large muffles are difficult to build, maintain and operate. At present costs of fuel and electricity, the radiant tube furnace is usually the lowest in operating cost.

Q. — What is the source of the atmosphere that is introduced in controlled atmosphere furnaces?

A. — Usually fuel gas is the base gas from which these atmospheres are prepared, whether for application to radiant tube, full muffle or electric furnaces. It is so treated as to provide the atmospheric constituents necessary for the refined heat treatment of steel, and is then known to the writers' organization as "DX gas."

Q. — Can this gas be made to meet all requirements of heat treatment of steel?

A. — Its composition may be varied and the apparatus in which it is prepared may be set to produce automatically and continuously an atmosphere that will meet all requirements from deoxidizing to actual carburizing of steel.

Q. — Is DX gas a safe gas to use?

A. — It is a very slow burning mixture of gases and practically non-explosive. It is not safe to inhale if concentrated, but there are no hygienic dangers attendant to its proper use.



Radiant Heating Elements

Coils of pipe, internally fired, and immersed in oil or metal baths (in other words, "immersion coils"), as first applied some 15 years ago, were the logical forerunners of radiant heating elements adaptable to industrial furnaces. However, it was obvious that the mere removal of an immersion coil from its moderately hot liquid bath did not turn it into a successful radiant element. The logical unfolding of the necessary qualities required not only a highly improved alloy to replace refractory muffles at high temperatures and reduce costly breakdowns to an acceptable minimum, but also required "prepared atmosphere" gases to protect the work and, lastly, the discovery of delayed combustion to heat a long tube, end to end, without hot spots.

In practically all fuel fired furnaces heat is transferred to the work by conduction from the furnace hearth, by convection from the gases contacting with the surface of the work and also to a great extent by radiation from the walls, roof and the gases surrounding the work to be heated. Owing to the fact that combustion gases react with the surface of the steel, modern improvements have had to do with controlled atmospheres and radiant heating. Radiant heating, in its simplest form, is the emission of heat waves from a hotter body, the radiant element, to the receiving body, the work in the furnace. The theoretical amount of heat transmitted is expressed in the equation

$$Q = pcAT^4$$

in which Q is the value in B.t.u. per hr.; p is the emissivity factor, varying with the nature of the surface; constant $c = 1.723 \times 10^{-9}$; A is the area, and T the absolute flame temperature, degrees F. + 460.

Transmission of radiant heat from incandescent gases does not closely follow this fourth-power law with respect to temperature, because the radiation from gases depends upon their concentration or the thickness of the stream of gas, and so the emissivity varies as the conditions of combustion fluctuate. Consequently the type of combustion ordinarily used in open heat treating furnaces would not lend itself to controlled radiation. If we were to use a premix or strictly luminous flame and depend upon its characteristics to transfer heat at a high rate by radiation, we would not only violate certain principles of combustion but the performance of such burners in actual practice would not meet

our standards of fuel economy or ease of operation. If internally fired in tubular heating elements, premix or nozzle mixing burners will cause excessively noisy vibrations due to the rapid rate of flame propagation. A strictly luminous flame burner in the same situation will result in imperfect combination of the hydrocarbon particles with the induced air. In the latter case the hydrocarbons in the fuel gas are first oxidized to alcohols, then to aldehydes, and finally to carbon dioxide and water vapor. (This theory of hydroxylation accounts for the fact that the odor of formaldehyde is always noticeable when starting up a cold furnace.)

A high rate of transfer of heat by radiation from a gas flame depends upon the liberation of enough carbon particles at incandescent temperatures. This can be accomplished by using highly preheated air or by admitting the gas and air in separate streams and at low velocity, so that the hydrocarbons are "cracked" near those surfaces between air and gas streams where combustion is actually occurring. This method of combustion, properly named "diffusion of flame combustion" was described by one of the present authors in *METAL PROGRESS* for September, 1932. It occurs at controlled velocity and within purview of the expected electronic rearrangements accompanying combustion reactions. The gas burns at the interfaces of the gas and air streams; microscopic particles of carbon (on the order of 0.000012 in. diameter) unite with oxygen and produce a highly radiant source of heat. Com-

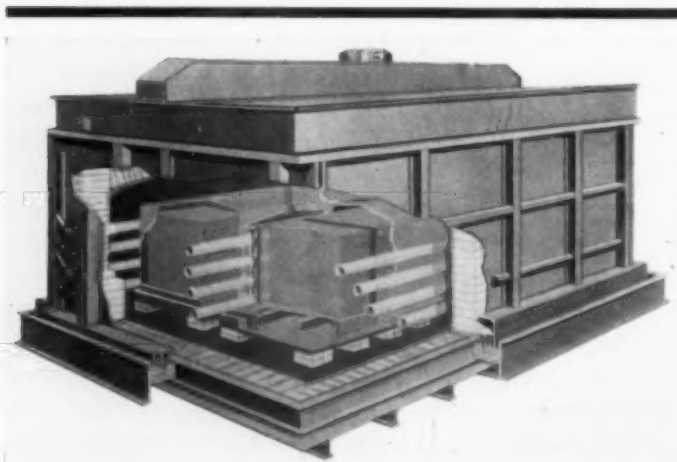
bustion occurs and will propagate at a constant rate throughout an allocated length. Obviously, this type of combustion with its high rate of heat emission and its application to radiant heating elements represents not only a contribution to the theory of radiant heat transfer but also a definite means for the plant operator to attain those qualities in fuel-fired heating operations which heretofore have been attributed to electricity.

Heat Resistant Tubes

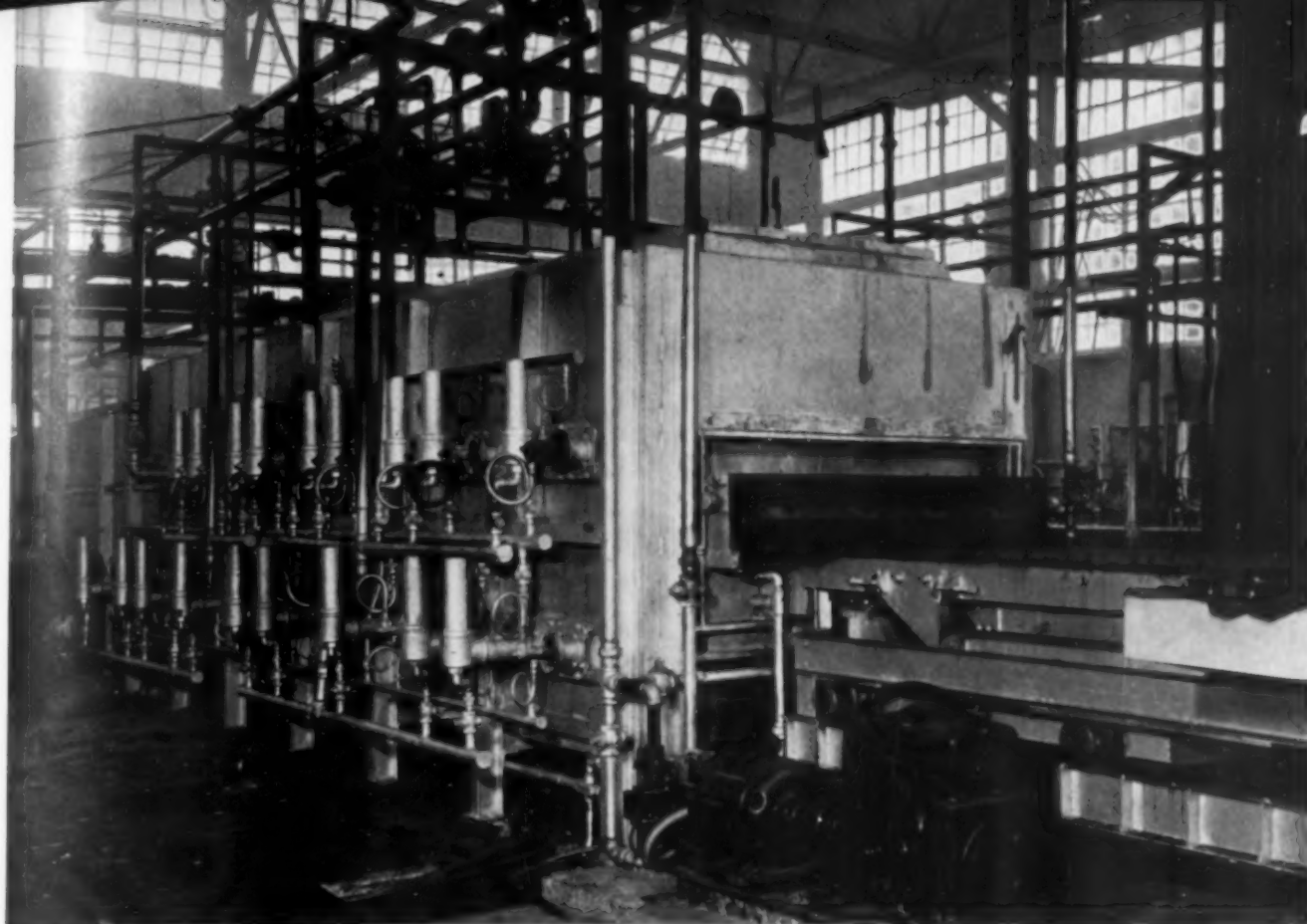
Radiant tubes or elements for a given furnace operation are usually made of heat resisting alloys (high chromium-iron or chromium-nickel-iron) and operate at all times under negative pressure — which incidentally is a protection against any combustion gases escaping through a crack or a joint into the furnace. Negative pressure is established by means of an eductor at the discharge end, as described in an article by W. C. Owen on "Heat Treatment of Spring Leaves" in the March issue of this magazine. The gentle suction produced at the burner end permits the fuel gas to unite with the combustion air at very low velocity and the diffusion flame so procured proceeds at uniform speed as the gases flow toward the discharge end where the completely burned products of combustion may be further utilized for preheating or drying purposes or, if occasion demands, discharged into the atmosphere. Thus, without sacrificing any uniformity of heat liberation, radiant elements

present an extraordinary means for applying heat where controlled production is contingent upon uniform heat distribution and freedom from harmful furnace atmosphere.

Heat treatment of steels at annealing and normalizing temperatures is influenced by a comparatively large number of factors of which temperature distribution, furnace atmosphere and period of exposure of the work treated are by far the most important. Scaling, decarburization and carburization of steel are caused by the presence of several constituents in the furnace atmosphere and the precise chemical reaction depends on the ratio of these constituents, resulting in scaling or carburization of the metal surface. Brief notes on ordinary conditions are contained in the catechism just ahead of this article. Should the metallurgical requirements call for a definite atmosphere to control grain structure and surface reactions, the use of "prepared atmosphere gases" is indicated.



Phantom View of Cover for Box Annealing Steel Sheets. Three rows of radiant heating elements are attached to the cover, and heated uniformly end to end by diffusion combustion of gas. Close fitting interior hoods, covering piles of sheets are necessary only when an especially expensive protective gas is needed, as the cover is tight



Hardening Furnace for Automobile Leaf Springs of Alloy Steel, Described in Detail in March Issue. Closely adherent and thin mill scale is retained unchanged by prepared atmosphere in through furnace, heated by banks of U-tubes (radiant tubes) placed above and below conveyor

Applications in Related Industries

There are some other interesting possibilities besides those already proven in practice in the heat treatment of steel. Short-cycle malleabilizing has been satisfactorily accomplished in electric furnaces under very accurate temperature control. Fundamentally, this process is concerned with improving the physical properties of cast iron by means of suitable heat reactions. There is no good reason why internally fired radiant elements could not be applied to this process where the desired change in the character of the carbon content is influenced by the input rate and the cooling rate of the comparatively large charge. The metal surface is decarburized by the ordinary furnace atmosphere depending upon the iron-carbon-oxygen equilibrium; excessive fuel consumption and the comparatively short life of annealing pots add further to the cost of this process. Internally fired radiant elements afford minute control of furnace conditions during the graphitizing and cooling periods, and it is hoped, as time goes on, that elimination of the pots, reduction in cleaning of the castings, and considerable shortening of the present cycle may be effected.

Similar results have followed the successful

introduction of annealing covers for sheet and coil annealing, heated by radiant tubes. (A sketch of the latter is shown on page 44.)

Proper temperature distribution and control of furnace atmosphere are also essential in heat treating non-ferrous metals. The recent improvements in quality and finish of copper, brass and nickel-silver, brought about by the use of inert or reducing atmospheres, may be further enhanced by the direct application of radiant heat. No muffle is required to protect the work and the elements operate under minus pressure with no danger of gases escaping into the furnace (the construction of which may be simplified) thus assuring complete smoothness of operation.

The effect of furnace gases upon vitreous enamel, on the bonding of ground coat and the physical condition of the gloss are chiefly attributed to the *source* of the heat. Electrically heated furnaces are costly to operate and frequent shut-downs are caused by short circuits through contact with the ware. Gas fired or oil fired furnaces necessarily require a protective muffle for quality work, as the presence of incompletely burned gases and water vapor is harmful. In order to demonstrate the advantages of radiant heat to vitreous enameling, the Research Committee of the American Gas (Continued on page 66)



Good Iron for a Good Mold

This photograph of pouring a lathe bed with high test, alloy cast iron, and its mate on page 49 were taken at Sterling Foundry by H. W. Forley of the Warner & Swasey organization

Lathe beds must be machinable but wear resistant, and stable in dimensions — no warping or twisting of ways can be tolerated. This class of castings is poured in core molds with high test nickel alloy iron

High Test Alloy Cast Iron For Machine Tools

■ IT IS THOUGHT that the following brief notes on methods used by the Sterling Foundry Co. of Wellington, Ohio, to make castings for Warner and Swasey machine tools and astronomical telescopes will be of interest as an exhibit of modern metallurgical practice in the foundry. High strength and machinability, coupled with hardness and wear resistance, dimensional stability, soundness and excellent surface — this combination of properties is not easy to achieve, yet has been done by close attention to small details and a demand for first-class workmanship and materials which have characterized the operations directed by Mr. Swasey and the late Mr. Warner since 1881. A quantitative measure of the excellence of the product is had from the fact that during 1934 the foundry scrap amounted to about 2½%, and the rejections of shipped castings were 0.52% — one in 200.

Of the 32 important points which I recently listed as major items to be controlled in highest grade foundry work, the majority have to do with operations prior and subsequent to the melting and pouring of the iron. Pattern making and maintenance, molding and core making, cleaning room practice, labor relations and general foundry economy rank large in importance, but are

somewhat aside from the metallurgical interests of most readers of METAL PROGRESS. Anyone interested in the human aspects of a small manufacturing plant, drawing intelligent, white American labor from a farming region, would do well to study the Sterling Foundry at first hand. Excellent working conditions and careful apprentice training have attracted and held a group of self-respecting workmen who take pride in owning their own homes and small farms. This requires more aggressiveness than the ordinary "pay-day" worker, and insures the innocent working man against want during business depressions.

Over-emphasis of this phase of the operations would not be easy; the human factor is paramount in a small foundry where production is too diverse for a high degree of mechanization and standardization. In this particular plant the personnel standards have been set by Samuel Hummel, the first manager, an able foundryman and executive who was also a born teacher of his craft. The happy result is that labor turnover simply is no problem at all.

Much has been written about the desirability of cooperation between designer and foundryman *before* the pattern is made. I can vouch for the many advantages of such a plan of action. A complicated casting like a lathe bed, with massive ways supported by a strong, rigid foundation and carrying a complicated gear box, cast integrally at one end, is a very difficult thing to make at best, and the combined experience and skill of

By F. J. Dost
Superintendent
Sterling Foundry Co.
Wellington, Ohio

designer, pattern-maker and foundry superintendent are required to lay out a plan of work which will reach the desired end. Eventually all must be convinced that the proposed unit can be made economically and satisfactorily, and the foundryman then has good ideas of how it should be done and proceeds to instruct his molders in the necessary technique.

Cleanliness is insisted upon in this shop — a relatively new note in foundry work. Molds and cores are swept clean as a ball-room floor before the flask is closed, and then *kept clean*. Even the cleaning room is a model, light and airy with washed windows, concrete floors and ample space around each job, ventilation so good that the painting department can put on the final touches in one side of the building, not even separated by a partition. Certainly no ambitious workman need feel degraded or his health impaired to work in such a place!

Large castings, such as a lathe bed, are cast in what is really a core mold. One of the photographs shows the pattern being lifted from a relatively small mold of this sort.

After the pattern is drawn, the surface touched up and thoroughly cleaned, it is washed with blacking and a camel's hair brush and baked. Baking is done by a series of perforated pipes (adapted to the cavities) burning a low flame of natural gas. Early drying is done with no cover, but later the partly baked cope is lowered over the drag with blocking between and both heated until the natural binder in the facing sand "sets" to a depth of about 3 in. At this time all surfaces of the sand have a density and hardness in keeping with the nature of the numerous cores which are then placed in position, to form the diaphragms and partitions in the finished castings.

As in all good foundry practice, the greatest care has been expended in the design of the mold and cores, their proper support, reinforcement, venting and gating, to insure that metal can enter fully into all cavities with the minimum of scour, and at the correct temperature so it will solidify without the defect of sponginess if too hot, or gas cavities if too cool. Slag and dirt from the ladle and pouring basin are excluded by perforated sheets of "skimmer tin" covering the gate — the latter itself a hard-baked core to prevent scour. Gates are so shaped as to give the incoming hot metal a swirling motion, thus holding particles of lighter slag and dirt at the center and top of an eddy, and the clean metal enters the mold cavity through a slot at the bottom.

Quality of High Test Cast Iron

Much publicity has been given to the higher strength cast irons, for great progress has recently been made in this direction. For instance, the standard specification of the American Society for Testing Materials current in 1921 said, "When tension tests are specified, the tension test specimen shall conform to the following minimum requirements: (a) Light castings, 18,000 psi., (b) medium castings, 21,000 psi., and (c) heavy castings, 24,000 psi. tensile strength."

Contrast this with the revised specification for gray iron castings A48—32T, adopted three years ago, which lists classes according to tensile strength, ranging from Class No. 20 with 20,000 psi. minimum tensile strength up to Class No. 60, with 60,000 psi. minimum tensile strength. Warner and Swasey lathe beds are made of high test cast iron, Class 40 to 50.

Gray iron, microscopically, is a steel structure or matrix shot through by graphite flakes. Its strength is therefore affected by two principal considerations, first, the amount, size and distribution of the graphite flakes, and second, the strength of steel matrix. The latter, in turn, depends upon the amount of combined carbon and the alloying elements present. (Even in common gray iron there is plenty of silicon alloyed in the steely matrix.) In order to be free of hard spots which will interfere with machinability, the combined carbon must be distributed throughout the steel matrix as pearlite and not as larger particles of the hard carbide.

In ordinary castings this metallic matrix, which has of itself the tensile strength of rail steel (on the order of 100,000 psi.) is badly broken up by relatively large flakes of graphite, occupying 5 to 10% of the total volume. To produce a higher strength cast iron the total carbon, and therefore the *amount* of graphite, must be reduced, and this graphite must also exist in the form of a very large number of very fine flakes. In practice, total carbon is lowered by replacing a large proportion of high carbon pig iron in the cupola charge with steel (for lathe beds as much as 80% of steel rail is on the charge). The fine granulation of the graphite flakes is had by melting the charge very hot, since superheat produces the necessary number of crystallization nuclei.

When 20 parts of a selected pig iron containing about 3.5% carbon is melted with 80 parts of steel rails containing about 0.80% carbon, the mixture must absorb some carbon from the hot coke in order that the iron at the tap hole may

contain about 2.80% carbon (and this carbon, by the way, must be on the charge, over and above that necessary for combustion). On the other hand, contact between molten metal and hot coke in the cupola must be short, or too much carbon will be absorbed. The desired result can only be achieved by close control of the entire operation—careful proportioning of materials, charged in the proper order, melted quickly and tapped frequently, then held in large ladles under hot charcoal until properly cooled for pouring. Foxboro instruments are installed at the blower for controlling and recording the weight of air put through the tuyeres, minute by minute, so that combustion will be at the proper rate.

"Semi-steel practice," in melting iron, formerly used for lathe beds, required 50% or less steel in the mixture, and the greatest care was taken to control silicon rather than the microstructure of the iron. Silicon had to be low else the casting would have a porous structure, yet not so low that graphitization was prevented on light sections and corners. Faced with the necessity of maintaining machinability, the foundrymen would run the silicon up and risk an open grained casting. Present melting practice and the addition of shot nickel at the spout gives castings of high hardness (up to 269 Brinell) and great wear resistance, yet ready machinability and freedom from abrasive carbide particles. A typical analysis is

Total carbon	2.79%
Combined carbon	0.61%
Silicon	2.05%
Nickel	1.50%
Manganese	0.85%
Phosphorus	under 0.20%

If an old-fashioned semi-steel were made to that hardness, the casting could be machined only

with stellite tools and then only with the greatest difficulty.

Each lathe bed has a test block attached to it, and serial number and date cast on. Its dimensions and location in the core mold are such that its structure represents that of the critical section in the completed casting. Its fracture is studied at the time and the Brinell hardness measured, and it forms a permanent record and material for any desirable special chemical or microscopical examination.

Nickel alloys with the iron in the pearlite, strengthening and toughening the steely matrix without inducing brittleness or difficulties in machining. There is also evidence that it induces a fine distribution of the graphite flakes. It also improves the stiffness of the iron, since tests by the International Nickel Co. show that Young's modulus of gray iron is usually between 12,000,000 and 15,000,000 psi., whereas high test 1½% nickel iron has a modulus between 18,000,000 and 21,000,000, this being much nearer steel at 30,000,000, and thus will deflect or stretch a smaller amount for a given load than common gray cast iron. This is a most useful factor in maintaining the high accuracy built into a machine tool.

All large machine tool castings are rough ground on surfaces that are not to be machined, given an undercoat of paint, smoothed with quick-drying filler, and painted according to specification. This is done for two reasons. First it is better to paint a casting before it is soaked with oil in the machine shop, and second, the whole foundry takes pride in the sleek condition of the castings on the shipping platform. Lastly, everyone who handles them, clear up to the erection aisle, treats them with more respect.

In conclusion, it is hoped that this brief article may emphasize some features absolutely necessary for a balanced foundry operation, starting in with the pattern shop and ending with the cleaning room, but mostly depending on an enlightened management and an intelligent personnel.

Lifting Pattern of a Moderate Sized Lathe Bed From the Drag. Both cope and drag are washed and baked before cores are set



Chapter Chairmen

Bachrach



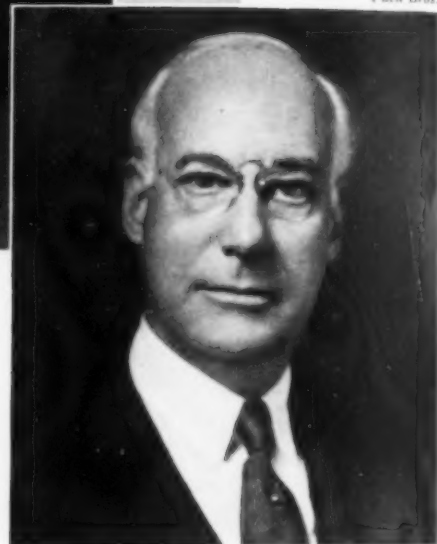
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Bachrach



R. S. Rose

Pach Bros.



Bradley Stoughton

Dexheimer



S. A. Silberman



T. H. Burke



H. A. Deane

**A. S. M.
1934-1935**

Six of them

SIX PORTRAITS and brief biographies were published in METAL PROGRESS last month of men who, by their vigorous leadership and unselfish devotion to their profession, are largely responsible for the continued success of the American Society for Metals. This month salutes a second group of Chapter Chairmen.

Bradley Stoughton

LEHIGH VALLEY CHAPTER boasted a chairman last season whose fame is preserved in "Who's Who" — and with good reason.

Bradley Stoughton was educated at Yale University's Scientific School and Massachusetts Institute of Technology, where he was also an instructor. He has been assistant to the lamented Henry Marion Howe at Columbia University, metallurgist for Illinois Steel Co., chief of the Cost Statistics Division of American Steel and Wire Co., manager of the Bessemer Steel Department of Benjamin Atha and Co., acting head of the School of Mines' Department of Metallurgy at Columbia University, and secretary of the American Institute of Mining and Metallurgical Engineers. Since 1923 he has been professor of metallurgy at Lehigh University.

His impressive list of memberships includes the A.I.M.E., American Iron and Steel Institute, British Iron & Steel Institute, American Electrochemical Society (president in 1931), American Society for Testing Materials, and Society of Chemical Industry, whose Grasselli Medal he was awarded in 1929.

He is a renowned chairman of A.S.M. technical sessions and has written a number of papers for conventions and chapter meetings. He has two books to his credit.

One piece of work in which Professor Stoughton takes great pride is his part in President Harding's successful campaign to enforce the eight-hour day in the heavy industries. Now admittedly of benefit to steel companies and workers alike, the eight-hour day at that time was vigorously opposed, and Mr. Stoughton's preparation of the iron and steel section of the book entitled "The Twelve-Hour Day in Industry" represented a serious sacrifice on his part.

H. A. Deane

A CREDITABLE JOB, to say the least, is the building up of a chapter from a low of 43 members to an all-time high of 190 members, but this is what was accomplished by the Tri-City Chapter (Moline, Davenport and Rock Island) under the leadership of Horace A. Deane in his year as chairman. An educational program was inaugurated and carried to a highly successful conclusion. Weekly discussions and demonstrations were held in addition to the regular monthly meetings, at which attendance averaged 140.

H. A. Deane has been employed by Deere & Co., Moline, Ill., since 1920, working first on the analysis of irons, steels, coals, oils, paints, and sundry products. When thoroughly saturated with the fumes of the chemical laboratory, he branched out into the metallurgy of the non-ferrous metals, cast iron, and steel. At present he is concentrating on cast iron production and research at various Deere & Co. plants.

Mr. Deane has held all the offices in the Tri-City Chapter at one time or another and is now graduated to the Executive Committee.

R. S. Rose

THE HISTORY of Robert S. Rose began in Pittsburgh, Pa., September, 1904, and excepting a sojourn in Bellevue (a suburb of Pittsburgh) this residence was found satisfactory until 1932.

Of Dartmouth College, University of Pittsburgh, and graduate school of Carnegie Institute of Technology, attended in the order named, University of Pittsburgh was the favored alma mater and aroused an affection which still persists.

Mr. Rose entered the business world with considerable timidity and anxiety in 1928 at the metallurgical laboratories of the Vanadium-Alloys Steel Co. Within the year he had joined the Pittsburgh Chapter of the Society. After four years grasping the complexities of mill and laboratory investigational routine at both the Vanadium and Colonial Steel Co. works, he was transferred to Springfield, Mass., in a sales-service capacity for the New England district. His membership, of course, was immediately transferred to the Springfield Chapter.

This was in 1932. That the Easterners realized the worth of this youngster is shown by the fact that they elected him vice-chairman in 1933-34 and chairman for the very successful 1934-35 season.

N. I. Stotz

PITTSBURGH is the birth-place of another one of the chairmen who, after varied adventures and travels, eventually returned there to help run that city's A.S.M. chapter.

Norman I. Stotz divided his education between Colorado School of Mines and Lehigh University, receiving his metallurgical degree from the latter institution.

His first work was in the metallurgical department of Detroit Steel Products Co., where he finally became night superintendent. From here he was abducted into the Army, and spent a year and a half in France in charge of heat treatment at the Base Repair Shops of the Motor Transport Corps. When that matter was finished he settled down at Braeburn Alloy Steel Corp. as chief metallurgist and has remained there ever since. In 1926 he was made general superintendent.

Mr. Stotz has been chairman of a great many of the Pittsburgh Chapter committees, has served continuously on the Board since 1928, and has just concluded his second year as chairman of the Chapter. He has promoted the idea of continuity of administration, necessary for the proper functioning of so large a body as the Pittsburgh group. He has also served on the Recommended Practice Sub-Committee on Tool Steels.

S. A. Silberman

POOR GOLF, bad bridge, and equestrian pursuits (horseback riding to you) are the hobbies of "Sill" Silberman, born in Chicago in the last year of the gay 90's. A brief period in his early years as an embryo Hoosier farmer was doubtless the incentive for later residence in Indiana, the State of Politicians.

After high school days in Chicago, where he worked to make both ends meet, came the machine shop, drafting, and then metallurgy. Although his B.S. obtained from the University of Illinois in 1923 was in chemical engineering, his greater love remained with electrical work.

He therefore spent some time in the testing laboratories of Commonwealth Edison Co. In 1924 he joined Claud S. Gordon Co. and is now sales and service engineer in the Indianapolis office, promoting the proper use of good pyrometric equipment.

He served four years on the Executive Committee of the Indianapolis Chapter before being made vice-chairman and then chairman for 1934-35.

T. H. Burke

THEODORE H. BURKE joined the New York Chapter in 1920, transferred to the Buffalo Chapter in 1923, and has been a loyal member ever since. He has served on the Executive Committee, was secretary, vice-chairman, and finally chairman for the past season. Ted is also a member of the American Institute of Mining and Metallurgical Engineers, American Society for Testing Materials, and American Foundrymen's Association—a scientific society "joiner", one might almost say.

Isaac G. Johnson & Co. was his first employer. He was with them for 15 years, working with steel, malleable and gun iron in the various departments of the foundry until he was made metallurgist. In 1923 when the Otis Elevator Co. established the Commercial Steel Castings Division at Buffalo, he was placed in charge of metallurgical control and research in the production of carbon and various alloy and stainless steel castings. He is also consultant on steel foundry practice.



One of the Many Things to See at the October Convention and Metal Show—Approach to Soldiers Field; Michigan Avenue in the Background (Kaufmann-Fabry Photo)

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Reading for August

Steel Manufacture

History of Lukens Steel Co., Insert in Iron Age, July 4.

Design and Construction of Hot Blast Stoves, Albert Mohr, Iron Age, July 4, p. 12.

Automatic Control of Open Hearths, J. K. Mawka, Blast Furnace and Steel Plant, July, p. 475 . . . Heat Loss Through Furnace Walls, C. E. Weinland, Transactions, A.S.M., June, p. 431 . . . Improving Open-Hearth Design (A Series), W. C. Buell, Steel, June and July issues . . . New Type of Suspended Tile for Furnace Roofs, Steel, July 22, p. 44 . . . New Temperature and Pressure Controls, Product Engineering, July, p. 250, 262.

Notes on Ingot Molds, T. Swinden, Paper for Institute of British Foundrymen . . . Copper Stools for Ingot Molds, C. E. Williams, Metals and Alloys, July, p. 169.

Descaling of Hot Steel During Rolling, Steel, June 24, p. 43 . . . Steckel Mill for Hot Strip, Iron Age, June 27, p. 12 . . . Defects in Strip From Continuous Mills, T. N. Keelan, Blast Furnace and Steel Plant, July, p. 461 . . . Chilled Rolls From Air Furnace Iron, Pat Dwyer, Foundry, July, p. 18.

Fabrication Processes

Cold Pressing and Drawing, a Discussion, Journal, British Institution of Automobile Engineers, July, p. 21 . . . Effect of Cold Work on Elastic Properties of Thick Plate, C. H. Gibbons, Paper for A.S.T.M., June meeting . . . Tube Bending on Production Basis, C. O. Herb, Machinery, July, p. 649 . . . Manufacture and Testing of Steel Forgings, W. H. Hatfield, Transactions of the Institute of Marine Engineers, June, p. 137.

Production of Powdered Metal of Low Melting Point, by R. W. Rees, Journal of Institute of Metals, June, p. 335.

Aging of High Carbon Steel, G. A. Ellinger, Transactions, A.S.M., June, p. 495 . . . Tempering High Speed Steels in Gas Oven, C. Foster Clark, Industrial Gas, July, p. 15 . . . Hardening Tool Steels in Controlled Atmospheres, S. K. Oliver, Steel, June 24, p. 30 . . . The Modern Heat Treatment of Steel Springs, Iron & Steel of Canada, May-June, p. 37.

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Effect of Molybdenum in Corrosion Resisting Steels, C. M. Loeb, Steel, June 24, p. 35 . . . Impact of 18-8 After Service, H. C. Cross, Paper for A.S.T.M., June meeting.

Machine Parts from Special Cold Drawn Sections, Machinery, July, p. 682.

Rail Fissures Correlated to Composition, Earnshaw Cook, Transactions, A.S.M., June, p. 545.

"High Hat" Steels, S. A. Knisely, Heat Treating and Forging, June, p. 280 . . . Saving Weight With the New Low Alloy Steels, J. C. Whetzel, (Paper for American Iron and Steel Institute, May meeting), Blast Furnace and Steel Plant, July, p. 464.

Physical Properties of Case Hardened Steels, O. W. McMullan, Transactions, A.S.M., June, p. 319.

High Chromium Tool Steel, W. H. Wills, Transactions, A.S.M., June, p. 469.

Improved Electrical Sheet, N. P. Goss, Transactions, A.S.M., June, p. 511 . . . Magnetic Properties of Iron, T. D. Yensen, Transactions, A.S.M., June, p. 556 . . . Magnetic Properties of Oxwelds With Alloy Steels, W. F. Hess, Welding Journal, June, p. 18.

(Continued on page 60)

MOLY



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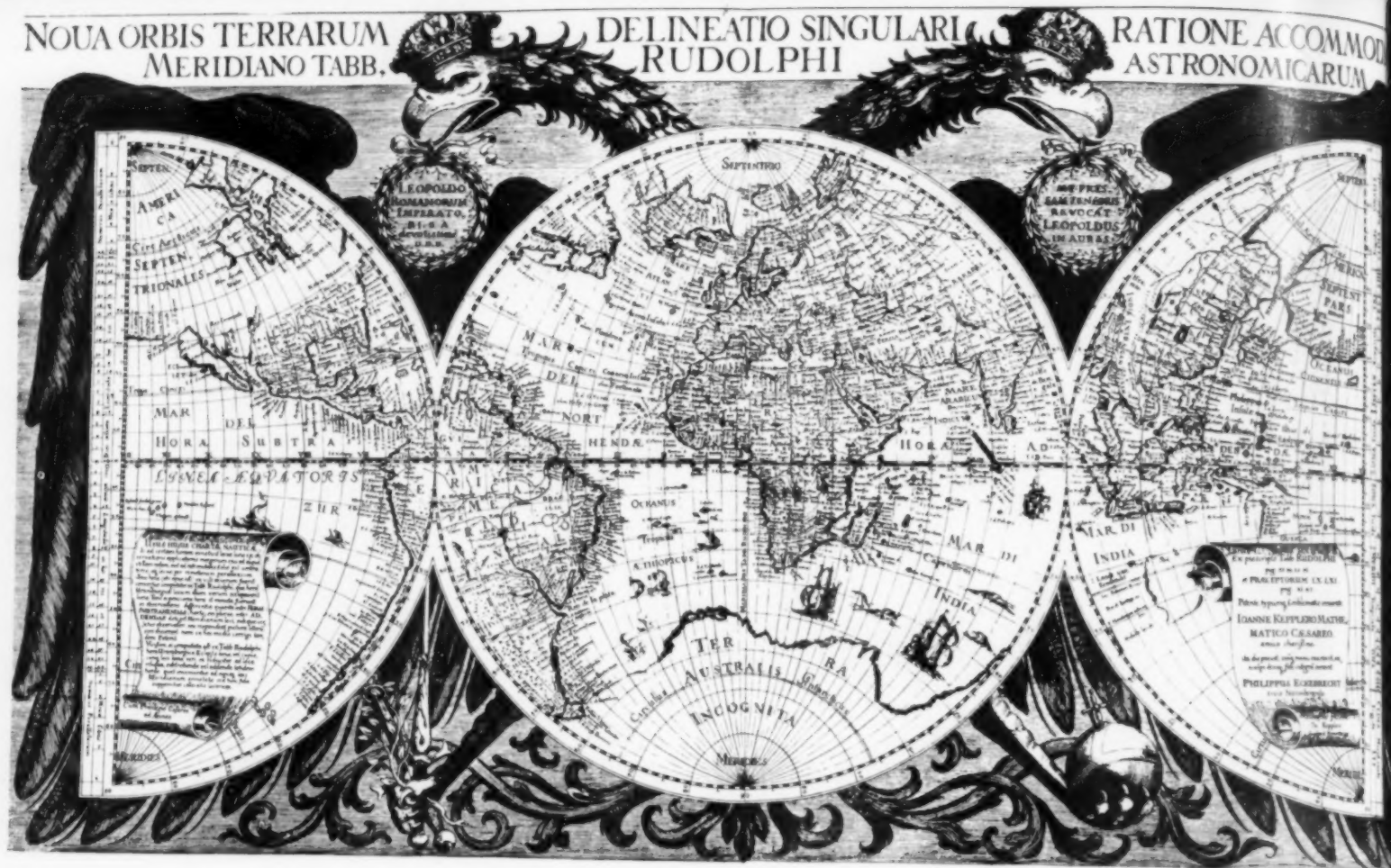
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Reading for August

Welding

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(Continued on page 62)

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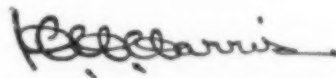
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Yield Point	72,000 p.s.i.	Elongation in 2 in.	25.5%

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Reading for August

Non-Ferrous Metals

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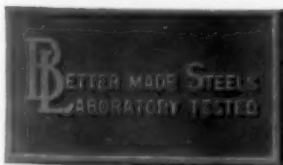
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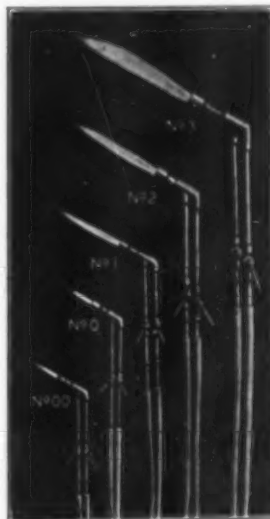
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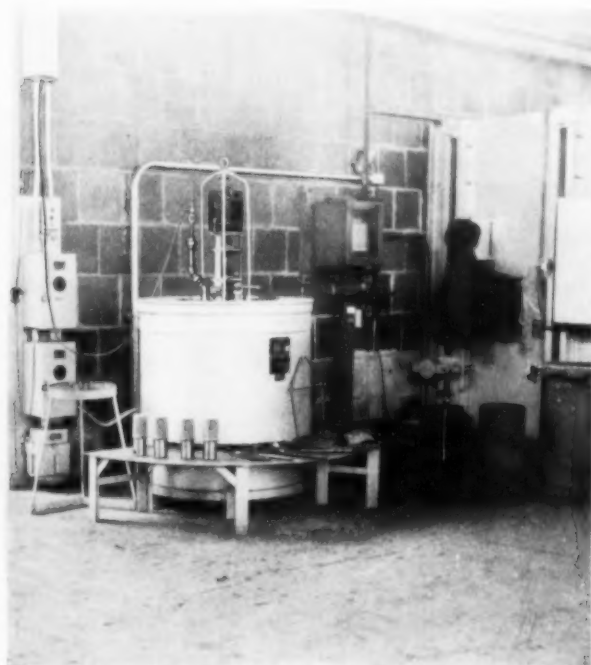


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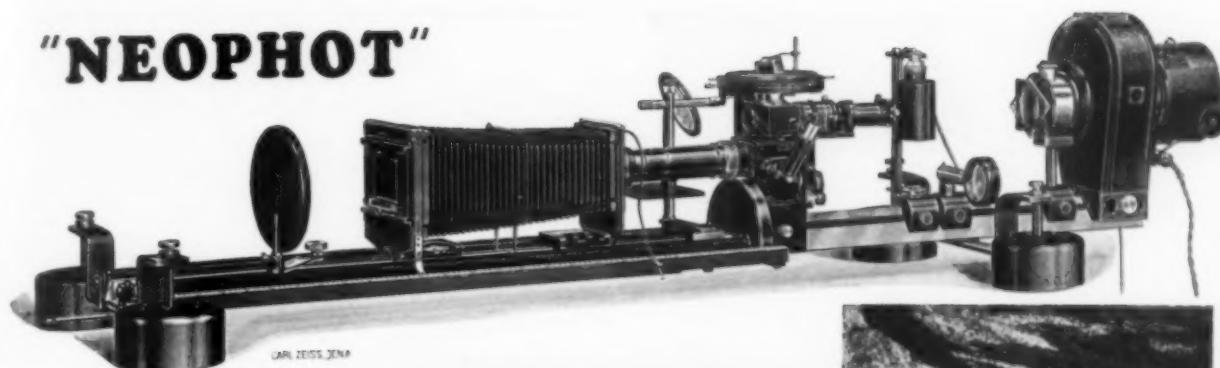
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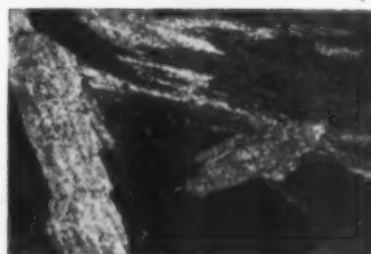
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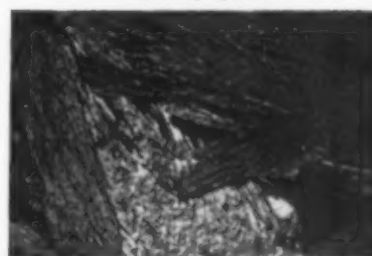
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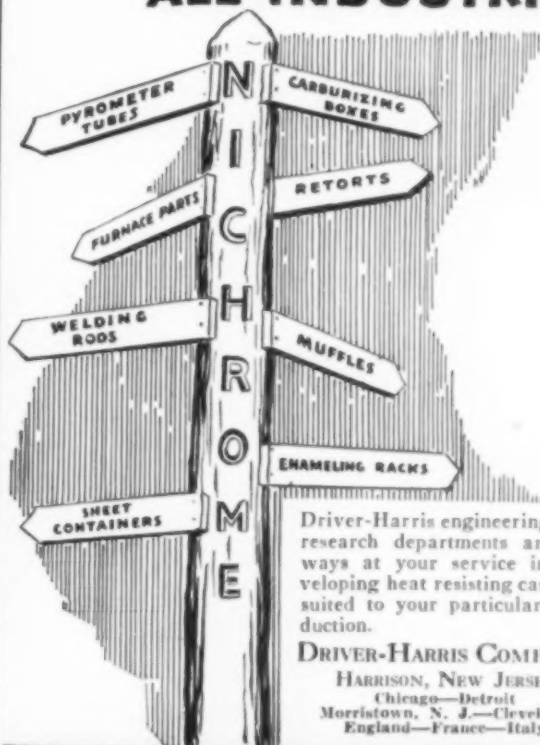
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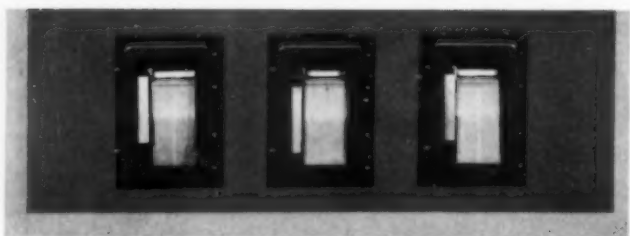
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Steel Components

(Cont. from page 27) means of a physiological galvanometer, a fine wire thermocouple welded to the sample, and a blast of compressed hydrogen for quenching medium. When the cooling velocity exceeded a certain value for any specific composition, only one thermal arrest was obtained, locating the austenite to martensite transition. The location ranged from 200 to 400° F., depending on the carbon content. The point was detectable in carbon steels with as low as 0.014% carbon! Therefore martensite is not formed by quenching until a low temperature is attained, and cannot be an intermediate stage in the austenite to pearlite conversion.

Summary

In summary, recent investigations show that austenite is an interstitial solid solution of carbon in gamma iron (face-centered cubic) which, at temperatures of about 800 to 1300° F. (400 to 700° C.) is converted to lamellar pearlite which may vary from fine to coarse depending on the temperature. Pro-eutectoid ferrite or cementite is also present, according to the composition of the steel. Martensite is an interstitial solid solution of carbon in tetragonal or body-centered iron and is not an intermediate product in the above transformation. If the austenite is rapidly quenched, the immediate result is martensite. A complete transition to martensite in quenched carbon steels is very improbable; both retained austenite, ferrite and cementite may also be expected to exist. When martensite is aged or tempered, iron carbide is precipitated leaving ferrite (body-centered cubic iron). The carbide particle size is related to the time-temperature factor and metallographically may be identified by the granular structure; this latter may range from extremely fine or even unresolvable to coarse, when it is known as sorbite. Therefore the constituents of steel are austenite, martensite, lamellar pearlite, and sorbite, the latter two being aggregates of cementite and ferrite. Certainly the number of components is relatively small compared to the multitude of supposedly individual phases which have been proposed and which are very difficult to distinguish or separate and actually represent stages in the continuous growth of ferrite and iron carbide.